The water quality status of the river aliens, Northumberland, assessed by macroinvertebrate sampling and the possible effects on the distribution of otters (Lutra lutra)

Eliades, Eula

The Water Quality Status of the River Allens, Northumberland, assessed by Macroinvertebrate Sampling and the possible effects on the Distribution of Otters (*Lutra lutra*).

by

Eula Eliades **B.S.c.**

A Dissertation submitted in partial fulfilment of the requirements

for the

Degree of Master of Science

Acknowledgements

I would like to thank my supervisors Dr. Nigel Dunstone and Dr. Tusi Butterfield for their help throughout the period of the study.

Special thanks to Tim Thom for all his help and encouragement and to Ian Downey for his help with statistical programmes. Also thanks to Rob Strachan. I would also like to thank the staff at the NRA for their assistance with water quality information on the River Allens.

Special thanks to my fellow M.S.c. Ecologists.

I would also like to thank all the land-owners who gave me access to their land.

Contents

1.0 SUMMARY

The zinc polluted River Allen catchment in Northumberland was surveyed for evidence of otters. The current water quality status was investigated and the possible effects of pollution on the distribution of otters discussed.

The water quality status was assessed by means of macroinvertebrate sampling using a kick-sampling technique. It was found that the West Allen was quantitatively and qualitatively inferior to the East Allen. There was a lower density of invertebrates and a less diverse fauna on the West Allen compared to the East. This correlates with the pollution status of the rivers. Data from the National Rivers Authority reported that the West Allen is more heavily zinc polluted than the East Allen. The lowest zinc levels were found on the main River Allen.

An otter spraint survey of the River Allen catchment revealed evidence of otters on the main River Allen and on one of its tributaries, the East Allen. No evidence of otters was found on the West Allen. The habitat characteristics of the River Allens were recorded and an attempt was made to relate the habitat variables to the distribution of the otters. Tentative judgements of the habitat preferences of otters are discussed.

Analysis of spraints revealed that the diet of the otters on the River Allens was comprised mainly of fish. Eels (*Anguilla anguilla*) formed the major component of the diet, followed by perch (*Perca fluviatilis*) and then salmonids.

2.0 INTRODUCTION

2.1 General Introduction

Otters exploit a wide range of aquatic habitats including estuaries, rivers, streams, lakes, marshes and coastal areas. Some of these waterways are rich in the otter's main food supply, fish, while others are less productive. This factor has a major effect on the distribution and movements of the otter, in particular the distance over which they travel in search for food and may also, together with other factors, influence their social behaviour (Melquist & Hornocker 1983). In the north-east of England one of the strongholds of the otter populations is found on the River North Tyne. However even within this area the otter population is fragmented. The River Allen has not been included in past National Otter surveys. However the South Tyne has and evidence of otters was found (Strachan pers. comm.).

Historically the rivers in the north-east have been some of the finest in England for migratory salmonids (*Salmo* spp.). Surveys of juvenile fish were carried out by the former Northumbria and Yorkshire Water Authorities in the period 1985 to 1989. Results were assessed in conjunction with spawning surveys and catch statistics to provide information on the nature, location and size of the stocks of wild migratory salmon (MAFF 1991).

Towards the end of the last century, the River Tyne was rated as one of the most famous salmon (*Salmo salmo*) rivers in England. In both 1871 and 1872, over 120,000 salmon were said to have been taken by nets operating in the lower reaches of the river, the estuary and in the sea at the mouth of the river. Rod catches of 2,200 to 3,200 salmon were recorded for several years in the early 1880's. However, by the turn of the century there had been a serious decline in the catches and this continued until the 1940's. Net fishing in the river and it's tributaries was banned in 1934, but no significant improvement in catches was seen until the water quality in the estuary was improved in the 1970s. Rod catches of both salmon and brown trout (*S. trutta*) on the River Tyne have increased greatly in recent years. There is no evidence that the amount of angling has changed significantly but there has been an increase in the number of anglers making catch returns. This appears to indicate an increase in the number of adult fish returning to spawn. Spawning surveys in the past two years suggest that many redds, particularly on the North Tyne, have been heavily used. The survey indicates that salmonids are widely distributed in the system, except in some tributaries that are heavily polluted or inaccessible (MAFF 1991). The three tributaries entering the River Tyne around Newcastle, the Ouse Burn and the Rivers Don and Team, are still heavily polluted and migratory fish can rarely ascend them, except occasionally under flood conditions. In addition, two larger tributaries, the River Derwent and the Devils Water, have artificial barriers to upstream migration in their lower reaches. The catchment in the present study, that of the River Allen, has two major tributaries, the West Allen and the East Allen. There is an obstruction on the West Allen in the form of a weir at Whitfield. There is also a natural waterfall at Holmes Linn downstream of Sinderhope on the East Allen. Both of these obstructions present an impassable barrier to migratory fish. Both the East and West Allen suffer from heavy metal pollution, but the West is more adversely affected (Abel & Green 1981). This arises from disused lead mines which lead to increased levels of metals particularly lead and zinc in the water. These mines have not been in operation for at least the last fifty years but the problems of zinc pollution still persist. The South Tyne also suffers from similar pollution problems but to a much lesser extent than the Allen system. The River Nent which enters the South Tyne at Alston also suffers particularly badly from heavy metal pollution (NRA pers. comm.).

Surveys above the impassable obstructions on the Allen have revealed a population of brown trout (*Salmo trutta*). It would appear that large, adult brown trout reside in the main river but head into the tributaries to spawn as this is the where the majority of juvenile fish are to be found. Below the obstruction on the West Allen only brown trout have been reported although both juvenile brown trout and salmon have been found on the East Allen. It is known that both juvenile trout and salmon enter the Allen each year. In addition to salmonids a number of other species such as eels (*Anguilla anguilla*), stoneloach (*Noemacheilus barbatulus*) and stickleback (*Gasterosteus aculeatus*) have been located during electric fishing surveys (NRA pers. comm.). Eels in particular appear to be well distributed throughout the South Tyne catchment. The South Tyne catchment is also regularly stocked with salmon parr by the NRA. In 1992 2,500 yearling salmon were released at Plankey Mill on the main River Allen with a further 2,500 being put into the East Allen. In 1993, it is planned to introduce a further 10,000 at Plankey Mill and 10,000 at Catton on the East Allen (NRA pers. comm.).

2.2 Aims

The River Allen catchment consists of the main River Allen and its two tributaries the East and West Allen. The River Allens suffer, to varying extents, from zinc pollution as a result of past mining activities. The current water quality status was to be assessed by sampling the macroinvertebrate fauna. This was then be related to the abundance of the otters main food source, fish, and hence the possible effects on the distribution of the otter.

There are a number of factors involved in the decline of the otter population in Britain. The most important is pollution of the waterways but habitat destruction is also relevant. The aim of the present study was to employ the method of spraint survey as a broad indicator of the otter population status on the River Allens and then attempt to relate the density of spraint to habitat utilisation. This method was used by Mason and Macdonald (1983a). Kruuk *et. al.,* (1986) argued that the density of spraint cannot be correlated to the habitat features of importance to otters.

The present study thus focused on the effects of the following habitat variables: amount of suitable cover; number of potential holts; number of lying up places; amount of disturbance; number of mature trees and the effect of water quality, as measured by the macroinvertebrate fauna, on the distribution of otters on the River Allens.

3.0 WATER QUALITY

3.1 Pollution Status of the River Allens

Sampling of macroinvertebrate was chosen as the method to assess the current water quality of the River Allens. One reason for this was to make the study comparable to a previous investigation of these rivers by Abel & Green (1981). Freshwater environments are ecosystems whose biotas are characteristic in terms of types, diversity and relative abundance, of their organisms. Hence it is possible to assess the water quality of freshwater ecosystems by looking at the change from the characteristic type. Hynes (1960) provided a scheme for the effects on biotas of persistent heavy metal contamination and distinguished those from the effects of biodegradation of organic matter, whose input tends to be local and transient. These points are important because the subsequent evaluation requires a realisation that ecosystem change through environmental change is real and discernible, although the major changes it yields - visible deleterious change in biotas - tends to be considered less significant than chemical changes.

Some invertebrate groups have been found to be more tolerant of polluted waters, others are quite sensitive and some still are not drastically affected either way. In this way they can act as indicators of water quality of rivers, lakes and streams. Two main invertebrate groups were surveyed. These were the nymphs of stoneflies and mayflies.

3.2 Stoneflies

The Plecoptera, in general, are adapted to cool lotic habitats. Adult plecopterans are terrestrial and live from 3-4 weeks. The rest of the life-cycle is spent as an aquatic nymph typically in cool, clear streams, although nymphs are found also in cold oligotrophic lakes but always below $25^{0}C$ (Harper 1979). By virtue of such temperature requirements stoneflies are mostly restricted to higher altitudes or circumpolar waterbodies or spring-fed lowland streams. Restriction of stoneflies to cool clean habitats in which there is considerable water movement is thought to be connected to the high oxygen requirements of the nymphs as raising the water temperature or decreasing water circulation distresses them (Hynes 1976).

3.3 Mayflies

Ephemeroptera are unique insects in that they have two adult stages. Both are winged, short lived (1-2 hours to a maximum of 14 days) and do not feed. The subimago (dun) is a stage of sexual maturation in which the wings are semi-opaque and covered in minute hairs with longer setae on the margins. The mature adult (imago) that emerges when the subimago moults has much longer legs and cerci and wings that are clear and bare.

The aquatic mayfly nymphs go through a large number of moults as they grow, with most species having 15-25 instars. Estimates of some species reach as high as 50 instars (Fink 1980) and variations occur within single species. In general mayfly nymphs tend to live mostly in unpolluted lakes, ponds, streams and rivers where with densities of up to 10,000/m^2 they contribute substantially to secondary production (Clifford 1982). Their greatest diversity is in running water habitats in temperate regions, where they are important members of the benthic community (Brittain 1982). Very small amounts of organic pollution can sometimes, initially, increase the numbers and production of certain species while others are exterminated. Species of *Baetis* seem the most tolerant to pollution and these are used as indicators of water quality.

3.4 Water Pollution

Pollution is a term that describes changes in the physical, chemical or biological characteristics of water, air or soil that can affect the health, survival or activities of living entities (Miller 1988). Organisms can respond to pollution either acutely or chronically. Acute effects result in serious injury to, or death of the organisms shortly after exposure to high concentrations of a pollutant. Chronic effects are realised following exposure to low concentrations of a pollutant, the results of which appear over time. When streams are overloaded with heavy metal contaminants the sediments become anaerobic and/or laden with the heavy metals and the impact on aquatic insect communities can be severe.

Different types of pollution have different effects on the ecosystem. Water bodies that suffer from industrial pollution are generally characterised by high densities of chironomids and an absence of stoneflies and mayflies. Winner *et al.,* (1980) investigated a stream in Ohio polluted with heavy metals (Cu, Cr, Zn) for 8 years from a metal plating plant. He found that in the most polluted sections chironomids and tubificid worms were virtually the only taxa to survive. Near the source of the pollution chironomids made up 86% of all the insects collected whereas at less polluted sites downstream they made up only 10%. Mayflies were only to be found where pollutants were immeasurable and caddisflies increased at downstream sites of intermediate pollution severity. As there appeared to be a direct relationship between the proportion of the community composed of chironomids and the degree of pollution, Winner *et al.,* (1980) suggested that the percentage of chironomids in samples may be a useful index of heavy metal pollution. The aquatic insect assemblages above and below a point source of sewage and industrial effluent were examined by Learner *et al.,* (1971) in the River Cynon, south-east Wales. Again the upstream faunal assemblage was found to be more diverse, with mainly chironomids and oligochaetes dominating the downstream reaches. Saether (1980) similarly recorded significant increases in the number of chironomid larvae when looking at the effects of eutrophication on the benthic invertebrates of deep lakes.

There are several mechanisms which aid chironomids in withstanding the effects of pollution. They have a higher oxygen storage capacity because of the presence of haemoglobin (e.g. in *Chironomus anthracinus* and *C. plumosus*; Nagel & Landhall, 1978), and an ability to avoid heavy metals by burrowing into the sediment (Wentsel *et al.*, 1977). Other means employed to limit the impact of pollutants include: body and gill movements to enhance oxygen uptake (as in perlid stoneflies and ephemerid mayflies; Gauffin *et al.,* 1974); adjustment of life-cycle to avoid periods of pollution stress (e.g. *Ephemerella ignata*; Sodregen, 1976); having generation times short enough to avoid stressful periods (e.g. *Baetis* and *Nemoura*; Newbold *et al.*, 1980) and breathing at the water surface by means of tracheal tubes (various *Hemiptera*; Gauffin 1973).

3.5 Mine Waste

The harmful effects of mine contamination derived from spoil heaps on aquatic insects vary according to the type of mineral extracted, the size of the operation, the type of mine (surface or subsurface, hard or soft rock) and to a lesser extent the local topography and climate. Generally, subsurface mining is less damaging to aquatic systems as for each unit of mineral extracted, only one-tenth as much land is disturbed as would occur by extracting the equivalent unit from a surface mine (Miller 1988). The factors that affect aquatic insects most severely are the release of toxic substances, mostly heavy metals, increased silt loads and higher levels of acidity.

Most methods to asses the impact of mine effluents on aquatic biota have been based on upstream/downstream comparisons. One such study was by Norris (1986) to examine the impact of zinc contamination on the Molongo River, Australia. He found the insect diversity and abundance downstream severely impaired compared to upstream with the exception of leptocerid caddisflies, suggesting that leptocerids are somehow resistant to this type of contamination. Norris *et al.*, (1982) performed a similar study on a 170km section of the South Esk River, Tasmania where the effects of mine waste on aquatic insects could be detected over a distance of 80km. From these findings hierarchical and non-hierarchical classification systems were used to define three groups of aquatic insects based on their responses to mining effluents: (1) taxa that were abundant at both contaminated and uncontaminated sites: a leptocerid caddisfly and a baetid mayfly; (2) taxa that were most abundant at sites upstream from the source of pollution: four species of caddisfly and five species of caddis fly and (3) taxa whose numbers were highest at sites downstream from the contaminant: six dipteran species and four species of caddisfly. Thus dipterans, mostly chironomids, and many caddisfly species are known to withstand a variety of environmental stresses.

The time required for insect assemblages to return to their pre-pollution state following pollution disturbances can be in the order of many years for streams and decades for lakes (Miller 1988). The recovery of insect populations following cessation of mining activities even when combined with terrestrial restoration programmes, such as planting vegetation, is very slow. In one study, Matter and Ney (1981) compared the benthic invertebrate and fish communities between several streams. The streams that had been undisturbed by mining action for at least seven years still showed elevated levels of alkalinity, hardness, sulphate, conductivity and fine particle suspended solids compared to those streams which had never been affected. This was also reflected in the poor diversity of the insect and fish assemblages.

4.0 Otters

Otters are members of the weasel family, the *Mustelidae,* comprising small to medium sized carnivores which have short legs but comparatively long tails (Mason & Macdonald 1986). There are five subfamilies and otters belong to the *Lutrinae.* The Eurasian otter is of the species *Lutra lutra* (Davis 1978). The range of this otter extends from the west coast of Ireland to Japan and from Arctic Finland to North Africa and to Indonesia. Although commonly referred to as a river otter it can also live on the coast.

Otters are shy, retiring animals and in Britain are usually nocturnal. They spend the majority of daylight hours resting in holts (dens) or in above ground lying up places (couches). Most otters live alone or in small groups and direct contact between otters other than within the groups is infrequent. However otter have an effective method of indirect communication using scent (Lenton, Chanin & Jeffries 1980).

4.1 Home Range and Territories

Otters exploit a wide range of aquatic habitats. The home range is the term given to the area of land or water where a particular animal normally lives. This is best visualised over a particular time span, such as a season or a year. It is an area which needs to supply feeding and drinking places, resting sites, breeding sites and all the areas which connect these sites (Erlinge 1967a; Mason & Macdonald 1986).

The term territory differs in that it normally encompasses an area which the occupant is prepared to defend. This implies a more restricted area than that of the home range and it is also more difficult to determine it's boundaries. Defence does not necessarily imply physical aggression but can also be by the indirect method of using signs, usually in the form of spraints (Erlinge 1968a).

4.2 Social structure and Population Density

The abundance and distribution of resources, mainly food but also resting sites and mates, affects the otters social organisation, such as home range size, as well as density and patterns of movement. The abundance of food varies not only from one area to another but also from place to place within an otters home range. Generally adult otters are solitary animals and males and females will only come together to mate. Family groups may also occur. Usually the home ranges of adult male otters do not overlap but when they do the movements of males will tend to overlap in space and not in time. Moreover the degree of overlap is small in relation to the total size of the home range. The home ranges of males may overlap with those of family groups and also with those of females.

Overlap between home ranges tends to occur in areas of superabundant food supply. In Idaho Melquist and Hornocker (1983) found two adult females sharing the same range, and male ranges also overlapped considerably. The overlap was most marked during the spawning run of the kokanee (*Oncorhyncus nerka*), a salmonid species, when up to twelve otters congregated at the spawning beds in one area. The otters main food source, fish, does not occur in separate, discrete clumps but some areas will offer a greater abundance of food and these will be interspersed between areas of poor abundance. Therefore larger home ranges would be necessary where 'good' patches were spread out and smaller ones would be possible when they were close together. Little is in fact known about the distribution of food in the River Allen study but it seems reasonable to assume it is an important factor.

Males can increase their reproductive potential by increasing their number of mates. The best strategy therefore would be to defend a large territory with sufficient good habitat encompassing the ranges of several females, and to hold exclusive access to those females. Obviously the size of the range is limited as the larger it is the more difficult it will be to defend. These factors may explain the relatively large ranges of male otters' in Scotland (Green *et al.*, 1984) and Sweden (Erlinge 1967a), and why the edges of male otters' home ranges are not necessarily determined by good feeding areas.

4.3 Holts and Lying-up Places

Green *et al.,* (1984) differentiated between holts, which were underground dens, or couches (lying up places) which were areas above it. Holts include bankside tree root systems undercut by water to provide ledges and extensive caverns, heaps of rocks and stick piles.

Riparian vegetation is ideal for lying-up places. These can be distinguished in that they are used on a more temporary basis and thus can be above ground but still providing an element of cover. Hence suitable lying-up places include thick bankside vegetation, temporary piles of sticks or fallen logs and islands of gravel surrounded by scrub.

Resting sites are not often limiting to otter distribution. However, suitable holts and especially breeding dens may well be. Females may well be expected to choose less disturbed and thus more secure sites for their cubs and this may well influence the distribution of female home ranges.

4.4 Significance of Spraints

The fact that otters deposit more spraints than is necessary for elimination of waste materials suggests that they also serve some other purpose. Spraint is dispersed widely throughout a range. Many spraints consist of just a few bones and some mucus. Spraint is frequently deposited in a conspicuous place such as prominent boulders within or alongside the water, under bridges, on top of fallen logs and tree roots and concrete structures such as weirs and sluices. This suggests that they are positioned in such a way so as to communicate information with other otters. This could include information on the age, sex, breeding condition and status of the individual. Trowbridge (1983) showed that a tame otter was able to distinguish between the scent of both familiar and unfamiliar otters. In Sweden otters were more likely to intrude on a home range when fresh spraint was not present (Erlinge 1968a).

A clear sex difference was found in sprainting activity of captive otters by Hillegaart *et al.,* (1981). Males sprainted at least twice as frequently as females (7 times per hour when active). Another difference was that males tended to spraint near the edges of their enclosures whilst females sprainted near to the holts and when they had cubs mainly in the water. This suggests that spraints were concealed in order to prevent detection by predators.

In Shetland, Kruuk (1992) examined whether otters were using spraints to signal priority of use of resources to other group members. Sprainting was found to be seasonal and increased when prey availability was low. Sprainting rates did not differ between the sexes or with status, nor were spraints deposited more frequently near to territory boundaries. Sprainting was associated with the beginning of feeding bouts, as well as with the utilisation of other resources including fresh water and holts. Kruuk argued that spraints were deposited as signals to other otters that an area was presently being exploited. This would serve not only to avoid aggressive defence of a patch but also to indicate that the resources had already been partly depleted.

4.5 The Decline of the Otter Population

There has been a long history of the persecution of otters in Britain. The earliest pack of otter hounds is recorded from the thirteenth century. Historically, trapping and hunting with dogs were the only effective means of killing. Although these may have originated from attempts to control otter numbers it has long been considered a field sport and during the nineteenth and twentieth centuries sport has been the dominant motive for otter hunting by the rich and poor alike. The otter population was also under pressure from keepers in an attempt to conserve fish stocks. This may have led to local extinctions. By the end of World War II, numbers had recovered and the otter was comparatively common throughout the country (Stephens 1957). This coincided with a massive reduction in the amount of keepering.

In the 1960s several otter hunts reported poor hunting success (Lloyd 1962). In 1977 the 'Joint Otter Group' published a report on the otter in Britain listing ten pressures on otters that might have been the cause of the decline. These were: disturbance by humans; hunting; riparian clearance; pollution; disease; road casualties; severe winters; the increasing mink population; the impact of fisheries and killing for pelts.

Since then six major reasons have been proposed for the decline of the otter population. The majority of information on the status of the otter in England, Scotland and Wales comes from the National Field Surveys. The first surveys were carried out between 1977 and 1986 (Crawford *et al.,* 1979; Green & Green 1980; Andrews & Crawford 1986 and Green and Green 1986). These revealed that otters were absent from large areas of the country, in particular south Wales and parts of the north. The Highland region of Scotland supported healthy populations as did the north and west coasts and the western islands, but south and east-central lowlands revealed a decline in numbers.

4.6 Pollution

From an analysis of the otter hunt records Chanin and Jeffries (1978) concluded that the factor that best fitted the pattern of the initial decline of the otter was the use of the organochlorine group of pesticides, in particular dieldrin. Dieldrin and related products such as aldrin, endrin and heptachlor were introduced in 1955 for a wide range of uses including sheep dipping, seed dressing and mothproofing. Increased mortality and reproductive failure of seedeating birds and raptors, such as peregrine falcons and sparrowhawks, had already been linked to the use of these compounds (Prestt & Ratcliffe 1970 I; Ratcliffe 1984). In Sweden the decline in the otter population has been attributed to contamination with polychlorinated biphenyls (PCBs). Some of these chemicals are very persistent as well as highly toxic. They can be washed from soils through river systems where they enter the food chain form plankton to invertebrates and fish thus reaching otters and other fish-eating predators. Of thirty-one otters analysed between 1963 and 1973, 81% contained measurable quantities of dieldrin (Jeffries, French & Stebbings 1974), although only one otter contained a pesticide level considered to be lethal. In Britain the use of dieldrin was banned in 1981. Analysis of fish tissues from around the country in 1980-81 suggested that chlorinated hydrocarbon pesticides and PCBs are no longer a threat to otters (Hider, Mason & Bakaj 1982).

A further pollution pressure on otters is the contamination of fish and their prey with heavy metals, particularly mercury, cadmium and lead (Mason, Macdonald & Aspden 1982). At a majority of sites the authors found levels of heavy metals in fish sufficiently high to be a potential health risk to otters. Lead and cadmium in combination can cause inhibition of sperm production in mammals which could possibly lead to sterility. Hence although the effects are not directly lethal to the otters, the sublethal effects on reproduction still pose a serious threat.

4.7 Disturbance

The number of people participating in recreational activities involving waterways has greatly increased in the last thirty years or so. Although it is clear that the disturbance to the otters' habitat increased it does not follow that the otters have been adversely affected. One study focused on three indices of human disturbance: the extent of fisheries; population density and the density of campsites in parishes adjacent to the rivers (Macdonald & Mason 1983a). None of these factors was correlated with the density of otter signs. On the west coast of Scotland otters frequently are seen to hunt during the day ignoring the fishermen and tourists. Holts have even been found within a number of town boundaries (Green & Green 1980, Chapman & Chapman 1982). So despite their image of being shy and retiring animals it seems clear that as long as their habitat offers safe refuge otters will tolerate a certain amount of disturbance.

4.8 Habitat Destruction

Modern management of rivers is not always the most sympathetic to the needs of otters. The National Rivers Authority has a policy of systematically removing bankside trees in order to prevent flooding and bankside erosion. In north-east Scotland sprainting activity correlated with the presence of riparian trees. The dense root systems of certain trees such as ash and sycamore provide excellent holt sites. These were significantly associated with the density of otter signs (Macdonald & Mason 1983a). Otters prefer areas of dense cover both for holt sites and lying-up places. Many potential holt sites are likely to be removed during riverbank clearance. Coghill (1988) found that all the tree holts were within 19m of the waters edge and 75% of them were associated with trees leaning over the water, the places most vulnerable to modification by water engineers.

Thus although habitat destruction alone cannot account for the drastic decline in otter numbers it is an important factor in limiting the present populations and inhibiting recolonization of some rivers.

4.9 The Relationship between otters and mink

It has been suggested that the increase in numbers of the North American mink (*Mustela vison*) may be implicated in the decline of the otter. However closer inspection reveals that mink populations had increased after the otter decline (O'Connor *et al.,* 1977). Although the diets of the two do overlap the diet of the mink is supplemented to a large extent with mammals and birds (Gerell 1967; Channin & Linn 1980) whilst the otter is largely piscivorous (Erlinge 1969; Jenkins & Harper 1980).

In very severe winters Erlinge (1972) suggested that mink and otters in Sweden could compete for food. If there is competition, however, the otter is superior to the mink at exploiting aquatic food. Generally the degree of overlap in the diets of the two predators has been concluded to be insufficient to cause competition (Wise, Linn & Kennedy 1981).

Although habitats also overlap between the two animals, again this is not a significant factor. Moreover, not only are there areas where mink are rare and otters are still in decline but evidence from some areas shows that where otters are still abundant, mink are also to be found on the same waterways (Melquist, Whitman & Hornocker 1981).

5.0 METHODS AND RESULTS

5.1 Study area

The study site encompasses the entire catchment of the River Allens in Northumberland. This river catchment consists of the Rivers East and West Allen which flow northwards for approximately 18km before joining to form the River Allen at Staward Peel (O.S. grid ref. NY 800566). The Allen is approximately 8km long and is a tributary of the South Tyne. The source of the East Allen is at Allenheads (ref. NY 860433) and that of the West Allen is at Coalcleugh (ref. NY 800442).

The rivers East and West Allen drain adjacent valleys which were extensively mined in the 18^{th} and 19^{th} centuries for a variety of mineral ores. The land adjacent to the West Allen contained many zinc-bearing veins but only one such vein was mined on the East Allen at Swinhope. At the time of Abel and Greens' study in 1981 there were at least 20 sites of potential pollution on the West Allen including mines, mills and waste heaps. However, waste material was removed from the surface so the East Allen only had half the number of potentially polluting sites. Subsequently the West Allen contained considerably higher levels of zinc than the East Allen.

The River Allen is bordered by dense, mixed broadleaved woodland. Much of this area is owned by the National Trust and as such is protected and managed in a way sympathetic to conservation of wildlife. On both sides of the River Allen run footpaths which are quite heavily used by anglers and walkers particularly in the summer months. Further upstream, at Plankey Mill (O.S. grid ref NY. 796621) begins the Briarwood Banks Nature Reserve owned by the Northumberland Wildlife Trust. This area consists of many ash *(Fraxinus excelsior)*, wych elm *(Ulmus glabra)*, sessile oak *(Quercus petraea)* and birch *(Betula)* trees. The dense shrubs include holly *(Ilex* spp.), birdcherry *(Prunus padus)*, blackthorn *(Prunus spinosa)*, honeysuckle *(Caprifoliaceae* spp.) and guelder rose *(Viburnum opulus)*. The Trust has managed the reserve through a system of hazel *(Corylus* spp.) coppice and the wood thus produced is used for firewood, charcoal, kindle wood and basket making. The management regime employed allows more light to reach the woodland floor to encourage a richer variety of woodland flowers such as wild garlic *(Alium* spp.) and sweet woodruff *(Galium odoratum)*. A sympathetic management of bankside trees is to remove branches hanging over the water but leaving the root stumps to regrow. These serve as potential otter dens.

The river catchment of the River Allen, including its two main tributaries the West and East Allen were surveyed on two occasions. The first was over the period from 12thMay to the 28thMay 1993, when otter spraints were collected. Invertebrate sampling was also carried out at this time. At the same time a number of habitat variables and disturbance indices were recorded at 100m intervals along the river course.

The second period of fieldwork was in the last week of June 1993 over a period of six days. On this occasion the abundance and species of bankside trees were also recorded. Water samples were also taken and analysed for pH and conductivity. Dissolved oxygen levels were analysed *in situ.*

The study area is shown of Figures 5.1 (a-c). Figure 5.1 (a) shows the River Allen, 5.1 (b) is the West Allen and 5.1 (c) is the East Allen. The sites where spraints were found and the NRA water monitoring locations are shown on the maps.

Fig. 5.1(a) The River Allen

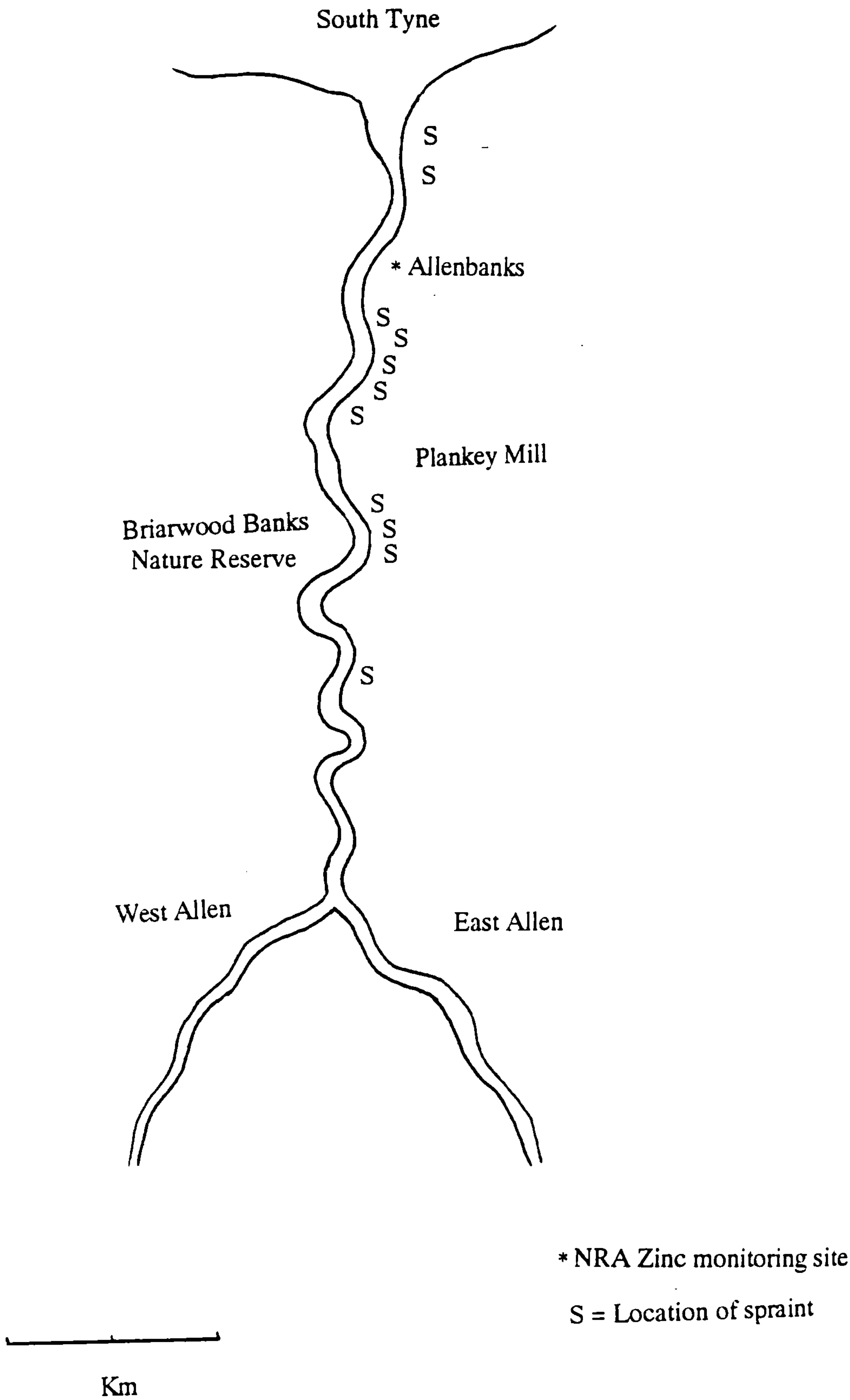


Fig. 5.1(b) The West Allen

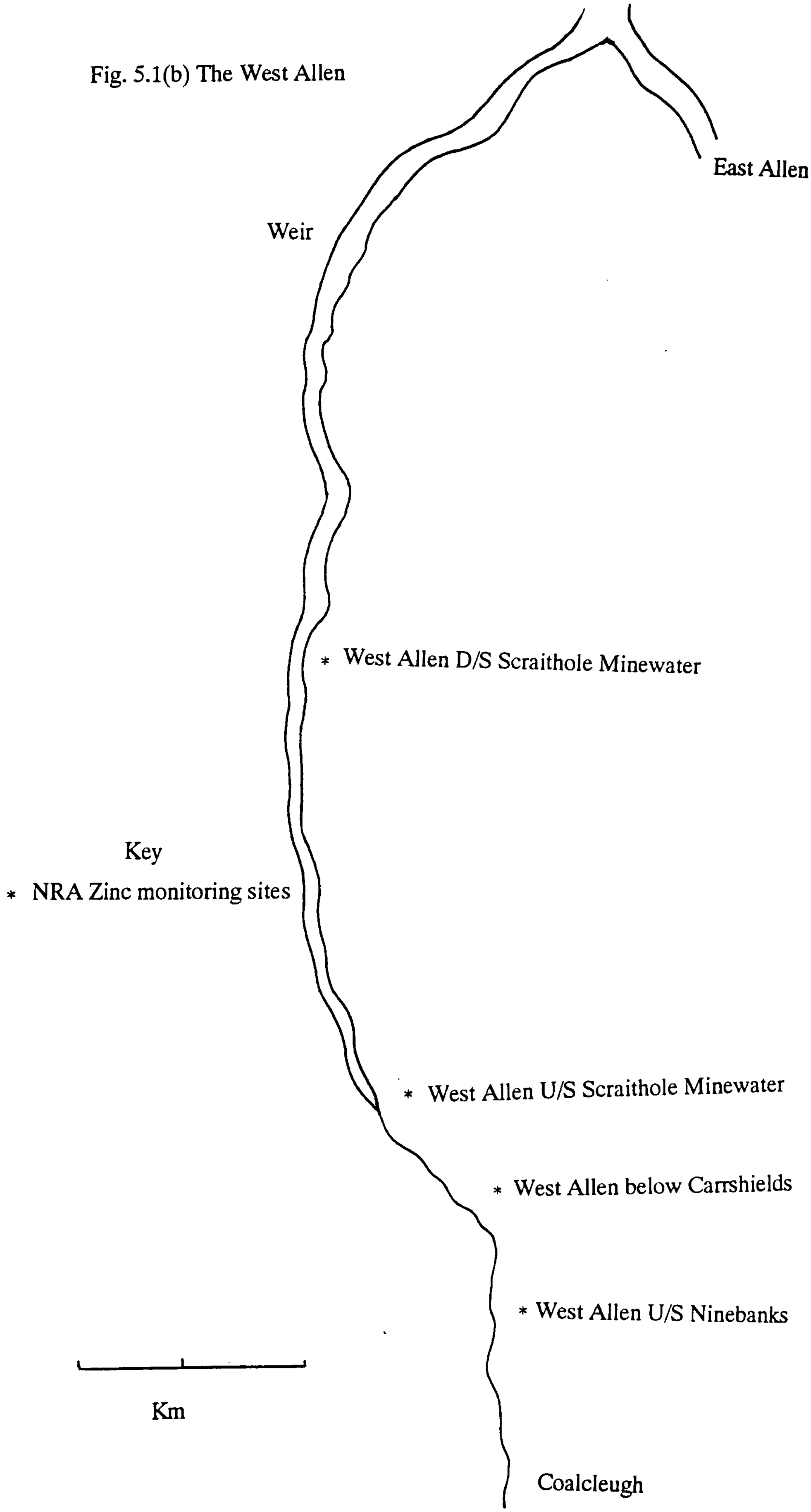
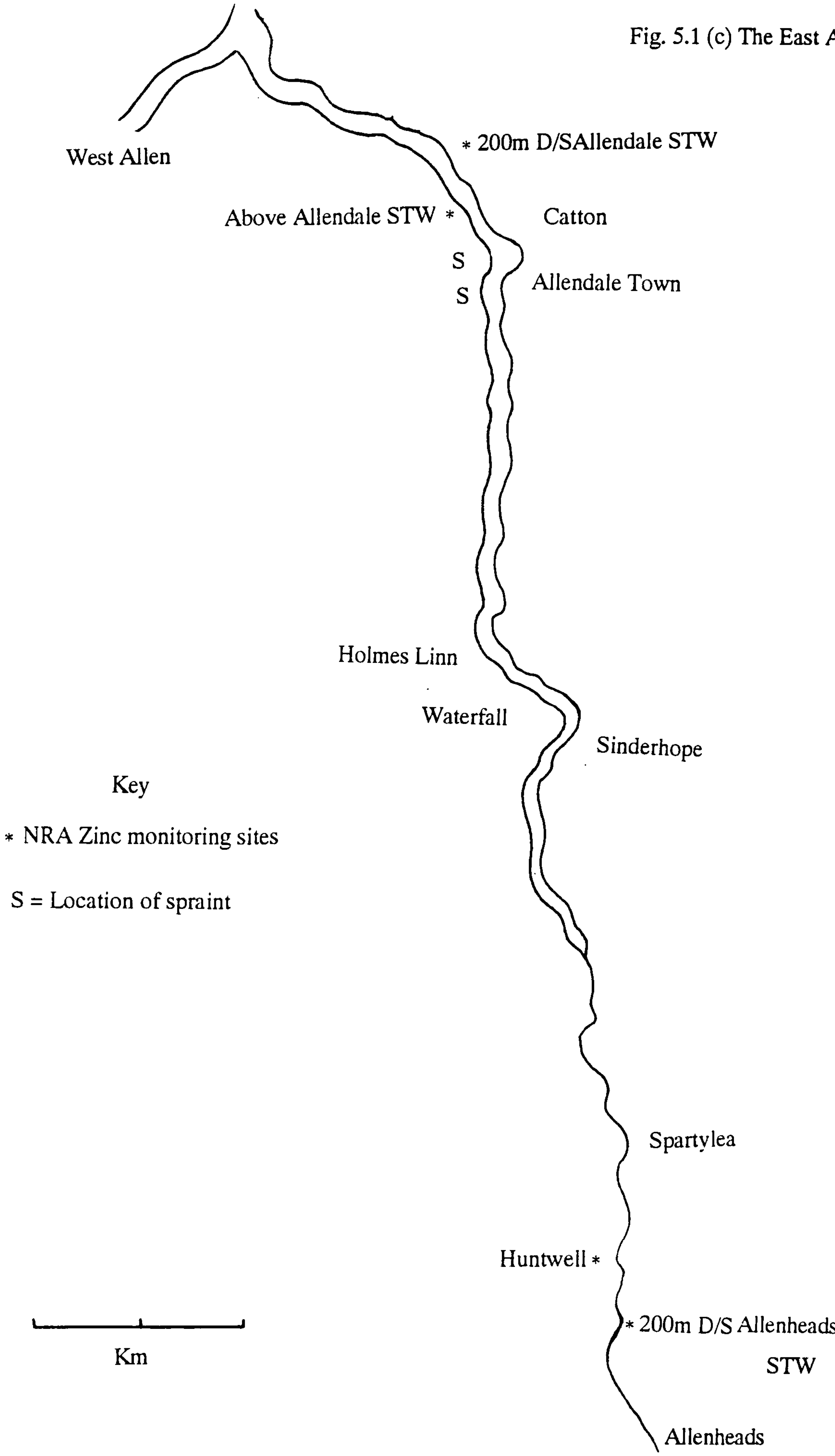


Fig. 5.1 (c) The East Allen



5.2 Invertebrate Sampling for Water Quality

The river was sampled for invertebrates at approximately 1km intervals using a standard "kick-sampling" technique (Hynes 1961). This is a qualitative method of collecting benthic macroinvertebrates. A hand net consisting of a 1mm mesh bag attached to a 0.3m by approximately 0.1m rectangular metal frame with a 1.5m long handle was the basic piece of equipment used. The net was positioned on the stream bed with the handle extended vertically out of the water. Feet were placed immediately upstream of the net and then shuffled from side to side by twisting the hips. This disturbs the substratum and has the effect of dislodging the fauna which are carried into the net by the current. This method has been standardised (D.O.E. 1976) and calibrated (Morgan & Egglishaw 1965; Frost *et al.,* 1971; Furse *et al.,* 1981). For *in situ* studies of benthic invertebrates kick-sampling is recognised as an effective method.

Three samples were taken at each site across the width of the river and each sample was collected for approximately one minute. The samples were bottled with a little river water and labelled. In the laboratory the invertebrates collected were washed through a 1mm mesh sieve in order to separate the animals from fine inorganic and organic matter. The fauna was then immediately preserved in 70% alcohol prior to identification. The invertebrates were all identified down to the level of family. The families of most abundant invertebrates, stoneflies and mayflies, were then identified to the level of species. Standard keys were used for identification (Ephemeroptera, Elliot *et al.,* 1988; Plecoptera, Hynes (1977); and Croft (1986), Freshwater Invertebrates).

5.3 Invertebrate Habitat

The following habitat variables were used to characterise the River Allens. These measurements were taken at approximately 100m intervals at the same locations as the invertebrate kick-sampling.

Depth

The depth was assessed wherever possible with a metre ruler placed in representative positions across the width of the river. When this was not possible a subjective estimate was made. Subjective estimates were made approximately 50% of the time.

Width

The width was assessed with the aid of a measuring tape but again subjective estimates accounted for approximately 50% of the total measurements made.

Substrate

The following index was used to assess the substrate:

1) Silt
2) Sand
3) Sand and Stones < 10mm
4) Stones >10mm < 100mm
5) As 4 but with occasional boulders
6) More frequent boulders
7) Large boulders and bedrock
8) Solid bedrock

6.0 INVERTEBRATE RESULTS

Canonical correspondence analysis (CANOCO) is a technique developed to relate community composition to known variation in the environment (Ter Braak 1986). The method was developed in order to address the problem in community ecology of how a multitude of species respond to external factors such as environmental variables and pollutants. The technique is an extension of correspondence analysis which extracted continuous axes of variation from species occurrences or abundance data.

The canonical ordination is a multivariate method of direct gradient analysis where ordination axes are chosen with reference to known environmental variables by imposing the restriction that the axes be linear combinations of environmental variables. Thus community variation can then be directly related to environmental variation. This technique detects the patterns of variation in community composition that can be explained best by the environmental variables, the data being presented as an ordination diagram where species and sites are represented by points and the environmental variables by arrows. The length of the arrow gives a relative measure of the strength of the influence of the environmental variables on the species distribution. Important environmental variables therefore tend to be represented by longer arrows than less important environmental variables. By looking at the angles between the arrows and the axis one may get an idea of the correlations between a species' abundance and the environmental variables.

In interpreting the percentage of variance accounted for by the environmental variables the aim is not 100% because part of the total variation will be due to 'noise' in the data. The numerical importance of the data is best judged by looking at its eigenvalue and its statistical validity as determined by a significance test such as the Monte Carlo Permutation test. This test involves the environmental data being randomly linked to the species data thus calculating the significance of the first eigenvalue. A significant result indicates that the species are significantly related to the environmental variables.

6.1 Analysis of Invertebrate Data

Detrended correspondence analysis reveals the relationship between the distribution of sites and that of the species data. A detrended correspondence analysis, DECORANA (DCA), plot was constructed for both the sites and the species distribution. Figure 6.1(a) is a DCA plot of site distribution showing how the sites lie in relation to each other. The sites are distributed in a fairly linear manner around Axis 1 but range quite widely around Axis 2. The West Allen shows two distinct groups. The group with position scores to the right of Axis 2, arranged along Axis 1, is of the lower reaches of the tributary just before it joins the River Allen. The other grouping shows the upper reaches of the West Allen, nearer to the source. A key to the taxa abbreviations is shown in Table 6.1.1.

The majority of the sites of the River Allen form a group mainly lying along Axis 1. The remainder of the River Allen sites are encompassed within the grouping of the East Allen sites, and indeed these sites do bear a greater similarity to the East Allen than to the West in that they are deeper and have a more silty substrate than is generally found on the West Allen. Finally the East Allen sites are of a more uniform character and are thus to be found in one major grouping along Axis 1, but in the opposite direction to the West Allen.

The DCA of the distribution of species in relation to each other is seen in Figure 6.1(b). The relationship between the species is less clear. However, some general characteristics can be seen from the diagram. Lying along Axis 1 to the right of the diagram there is a grouping of the species *Leuctra inermis, Diura bicaudata, Baetis buceratus, Leuctra nigra and Ecdyonurus torrentis.* All these species show a preference for a rocky substratum. Next to these *Amphineura sulcicollis,* Elmidae and *Isoperla grammatica* are characteristic of wide, deep and slow flowing areas of streams and rivers. Similarly the grouping to the left of Axis 2, namely *Rithrogena semicolorata,* Tipulidae, Hydropsychidae, Gammaridae, Molannidae, Leptoceridae *and Baetis rhodani,* have in common the tendency to be most abundant in slower sections of rivers and streams with a sandy or silty substratum such as is found in the River Allen and in the lower reaches of the East Allen. The other clear grouping is of the species which are characteristic of streams with a stony substratum, such as is found in the upper reaches of the East and West Allen. This group includes *Chloroperla tripunctata, Chloroperla torrentium* and the Simulids. However, the remaining species are also characteristic of such environments. Chironomids are found in most types of habitats.

The analysis was taken a step further by performing cannonical correspondence analysis (CCA) on the data. Figure 6.1(c) is a CCA ordination diagram showing the distribution of sites in relation to the environmental variables, to which arrows have been drawn. The Allen environmental variable makes the smallest angle with Axis 1 indicating its importance to the sites which lie along this axis. The River Allen sites fall mainly around the arrow of the environmental variable of the Allen but also around that of depth. This reflects the fact that the River Allen is a deeper river than its two tributaries. It is also wider and deeper and to some extent slower flowing, although this is not clearly reflected in the diagram. For the most part it has a stony substratum tending towards a fine silt. If the arrow for substrate is extended downwards the Allen sites can be seen to occur mostly around this end of the arrow thus indicating a less rocky substratum.

The sites of the West and East Allen tend to be associated to a large extent with Axis 2. The important environmental variables along this axis are the substrate, width and distance from source. The two tributaries are characterised by a more stony and rocky substrate. They are also narrower and tend to be faster flowing than the River Allen, reflecting the fact that they are close to the source of the river.

Figure 6.1(d) is a CCA plot of the distribution of invertebrate species in relation to the environmental variables. Some general patterns can be distinguished. *Baetis rhodani, Rithrogena semicolorata* and *Isoperla grammatica* were particularly abundant in the deep and slower sections of the East Allen. Moreover *Baetis rhodani,* and *Rithrogena semicolorata* together with Dixidae, Gammaridae, and Hydropsychidae was also to be found in the sheltered and deeper sites of the River Allen. Another grouping found mainly in the sandy and slow sections of the streams includes Molannidae, *Chloroperla torrentium, Leuctra hippopus* and Leptoceridae. *Leuctra inermis, Baetis buceratus, Chloroperla tripunctata* and Elmidae were most abundant in the stony sites of the West Allen. Although not clear *Leuctra nigra,* Brachycentridae and Ancylidae were most abundant in the silty and slow regions of the rivers. The remaining species, showing no clear trend, are generally to be found in the stonier sections of streams and rivers.

To test the null hypothesis that the true coefficient of a particular variable on an axis is equal to 0, the t-value of the regression coefficient of the variable can be compared with the critical value of a Student t-distribution (Ter Braak 1986).

In the present study the largest arrow on Axis 1 is that of the environmental variable of the West Allen indicating this to be an important variable. It has a t-value of 2.5 on the first axis which is just significant ($p<0.05$). The River Allen is also significant ($t = -3.2$, $p<0.05$) but in the opposite direction. The East Allen is also in the opposite direction to the West but is not quite significant ($t = -2.0$). However,, the arrows indicating the rivers are not strictly environmental variables but help to indicate the species' distribution. On Axis 1, although not significant, a trend is revealed in that the important habitat variables in relation to the species' distribution is the distance from source, the substrate and then the width. On Axis 2 the River Allen is significant ($t = -3.9$, $p<0.05$), followed by the substrate ($t = 3.2$, $p<0.05$) and the width ($t = 2.9$, $p<0.05$).

When the inter-set correlations of the environmental variables with the species' axes are examined the West Allen has the largest correlation on the first axis (0.69), followed by the depth (-0.38) and the East Allen (-0.36). The East Allen then has the largest correlation with the second axis (0.56), followed by the substrate (0.44) and the depth (0.39). The remainder can be seen in Table 6.1.2 below:

Table 6.1.2 Inter set correlations of environmental variables with axes

Environmental variable	Axis 1	Axis 2
Substrate	0.046	0.435
Depth	-0.375	0.380
Width	0.121	0.352
River Allen	-0.262	-0.055
West Allen	0.687	-0.375
East Allen	-0.356	0.561
Distance from source	0.091	0.354

The species and family distributions were significantly related to the environmental variables on Axis 1 ($p = 0.04$, Monte Carlo Permutation test). The arrows for environmental variables account in conjunction with the species points for 64% of the variance in the weighted average for the 26 species with respect to the 7 environmental variables.

The most important environmental variable not included in the above analysis is that of zinc pollution. It was not possible to measure this at each site of invertebrate sampling. However, detailed records of zinc levels on the River Allen catchment were obtained from the NRA. These reveal the continuing high levels on the West Allen in comparison with the East Allen. The zinc levels on the River Allen catchment are shown on the figures 6.1 (e-i) below. Figure 6.1 (e) is a comparison of the zinc levels recorded at various sites along the River Allen catchment from 1989 to 1993. Although the highest zinc levels in 1993 are recorded for the West Allen note that the East Allen sampling site above Allendale has zinc levels almost as high. The zinc sampling sites on figures 6.1 (f-i) are arranged in the descending order of zinc levels recorded in the River Allen catchment in 1993. Hence, note that the West Allen site upstream from Scraithole Minewater has lower levels of zinc than the East Allen site above Allendale.

Table 6.1.1 Key to taxa on which the multivariate analysis was performed

Abbreviation	Taxa
RHODANI	*Baetis rhodani*
BUCERATUS	*Baetis buceratus*
SEMICO	*Rithrogena semicolorata*
TORRENT	*Ecdyuonurus torrentis*
INERMIS	*Leuctra inermis*
NIGRA	*Leuctra nigra*
HIPP	*Leuctra hippopus*
GRAMM	*Isoperla grammatica*
BICAU	*Diura bicaudata*
TRIP	*Chloroperlida tripunctata*
TIUM	*Chloroperlida torrentium*
TAEN	Taenidae
DYTI	Dytiscidae
ELMI	Elmidae
HYDR	Hydropsychidae
LEPTO	Leptoceridae
MOLA	Molannidae
BRACH	Brachycentridae
LYMN	Lymnephilidae
ANCY	Ancylidae
GAMM	Gammaridae
SIMU	Simulidae
DIXI	Dixidae
CHIR	Chironomidae
TIPU	Tipulidae

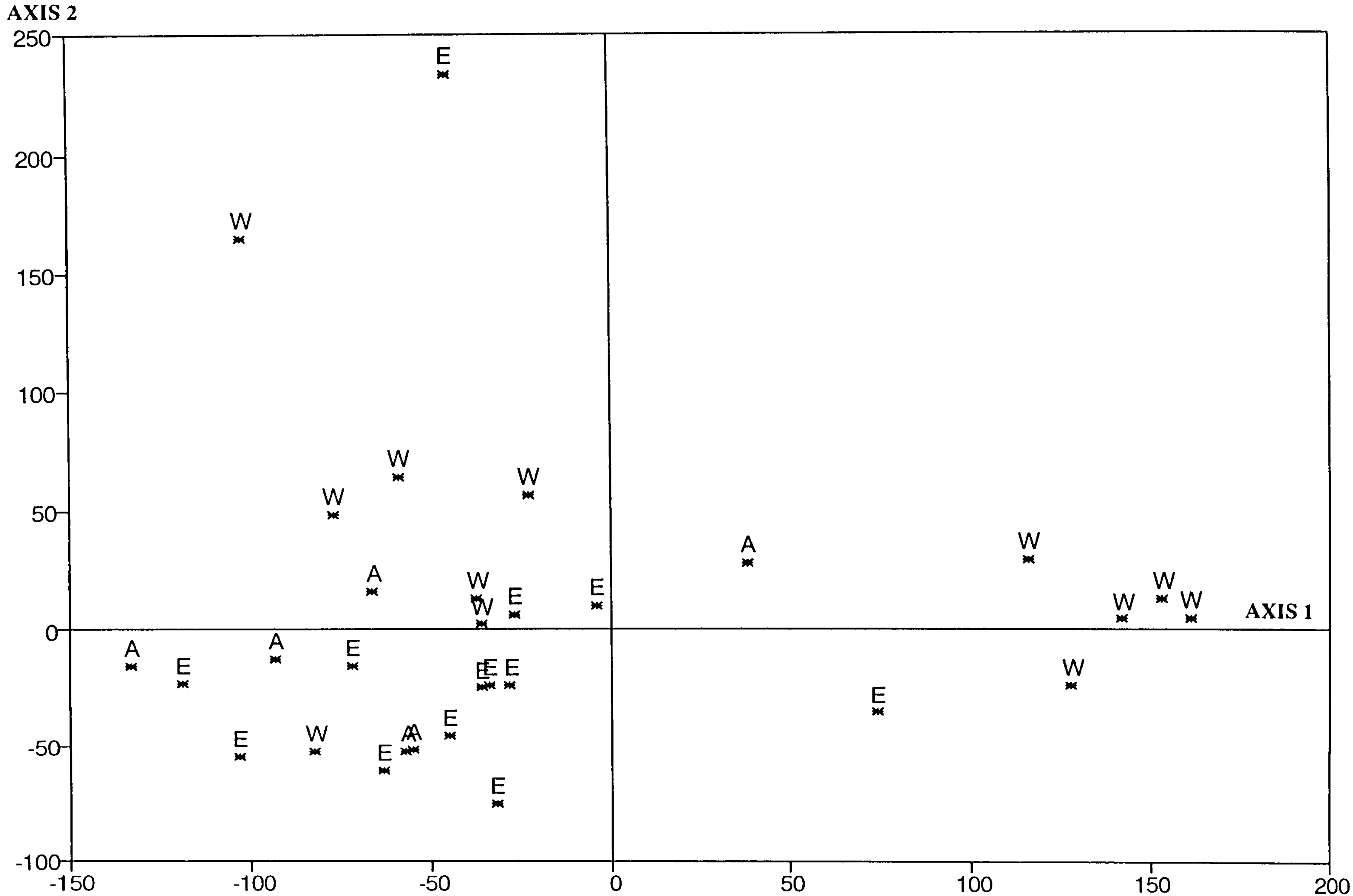


Fig. 6.1 (a) DCA showing the distribution of sites of the Rivers East, West and Allen in relation to each other

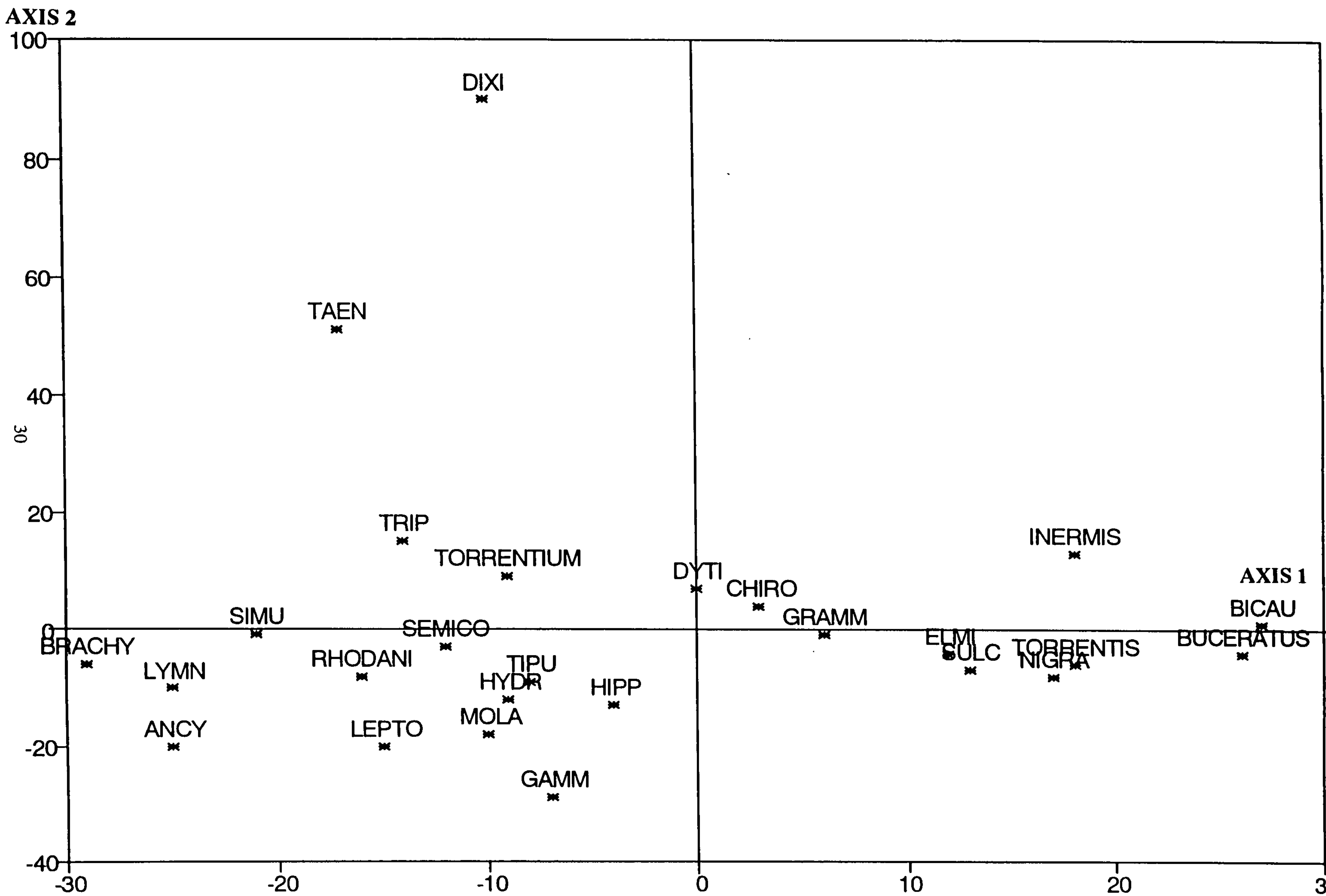


Fig. 6.1(b) DCA showing the distribution of species in relation to each other

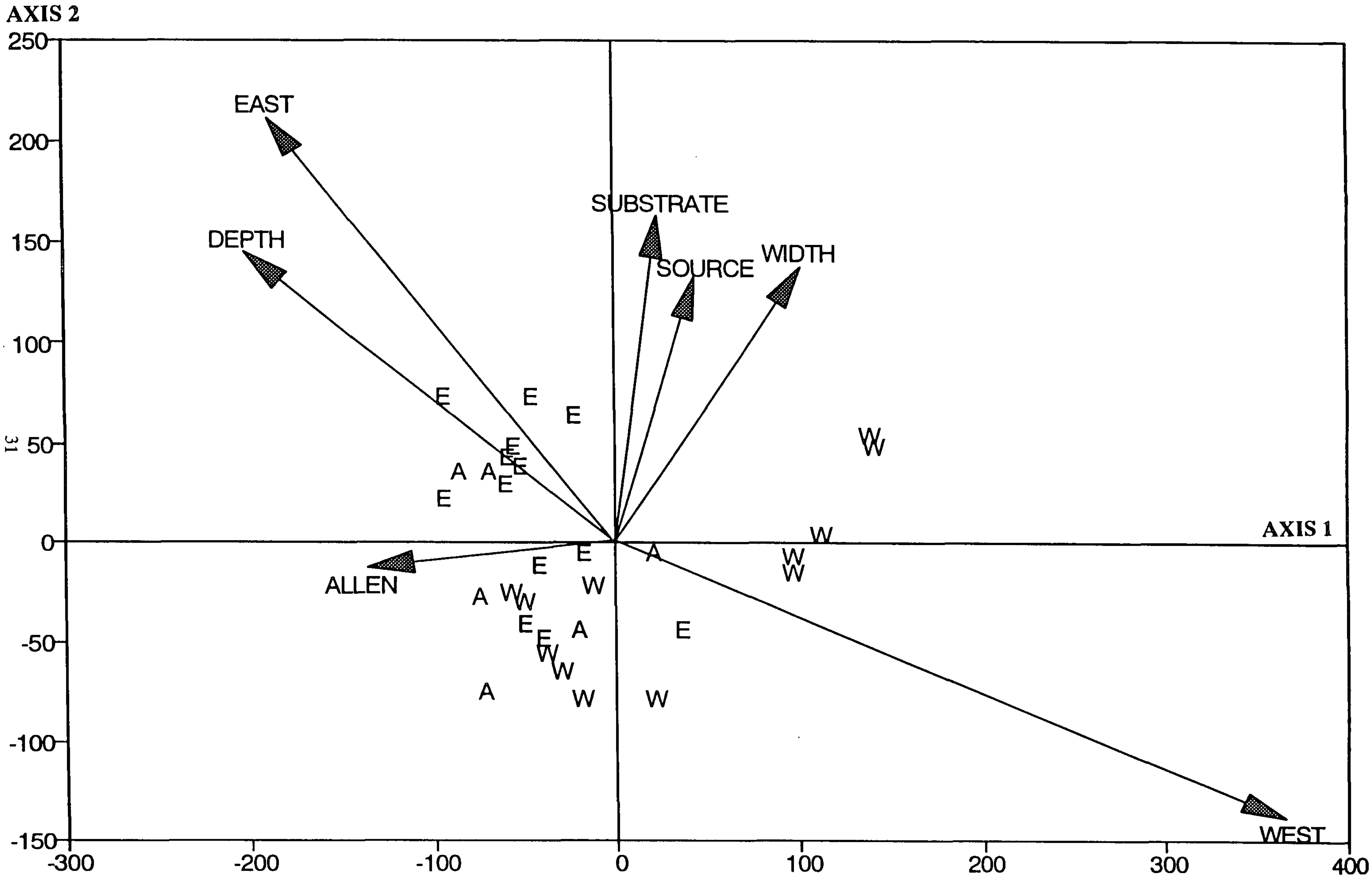


Fig. 6.1(c) CCA showing the distribution of sites of the Rivers East, West and Allen in relation to the environmental variables

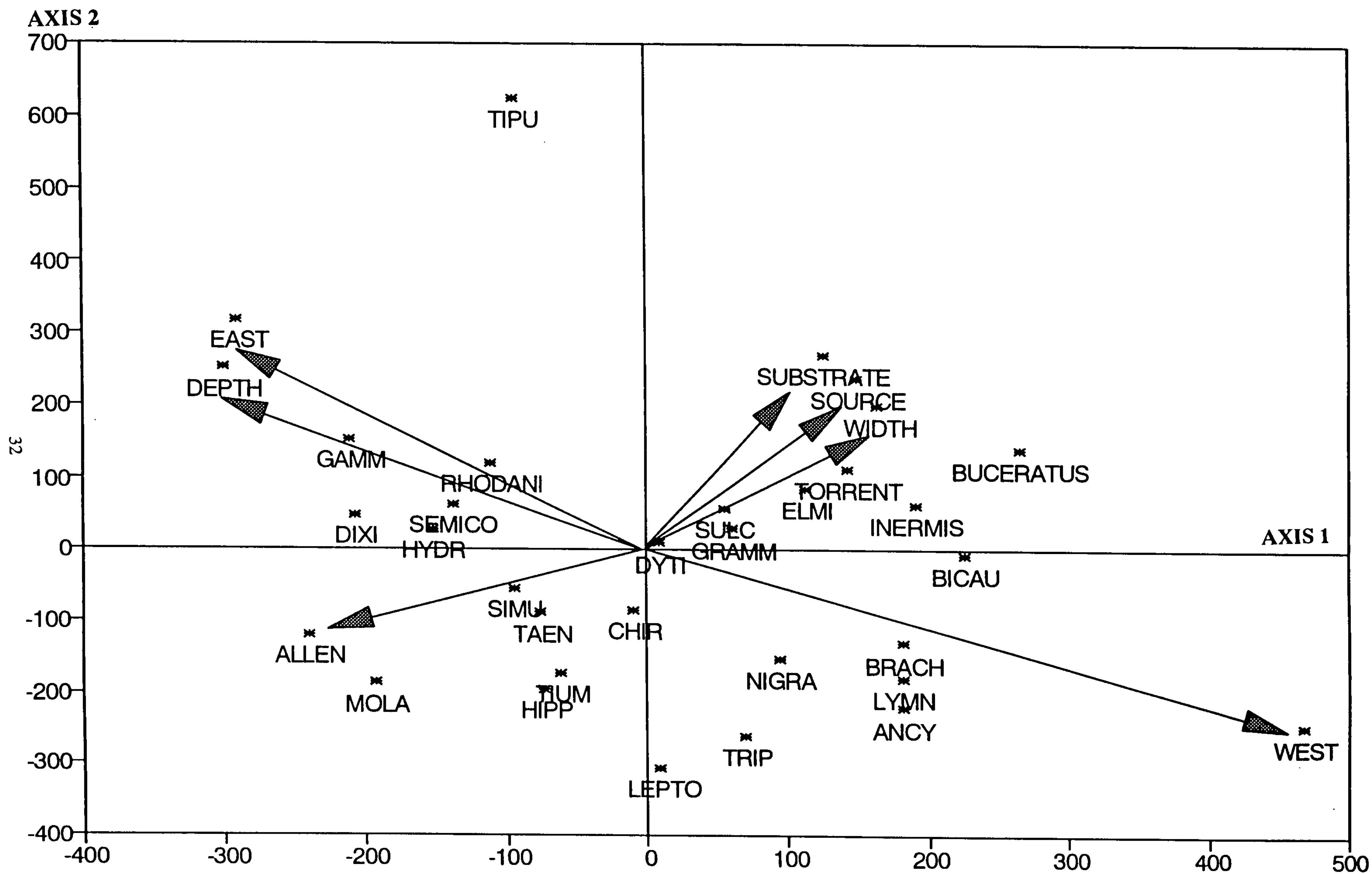


Fig. 6.1(d) CCA showing the distribution of species in relation to the environmental variables

Fig. 6.1 (e) A comparison of the zinc levels on the River Allen catchment from 1989-1993 (data from the NRA)

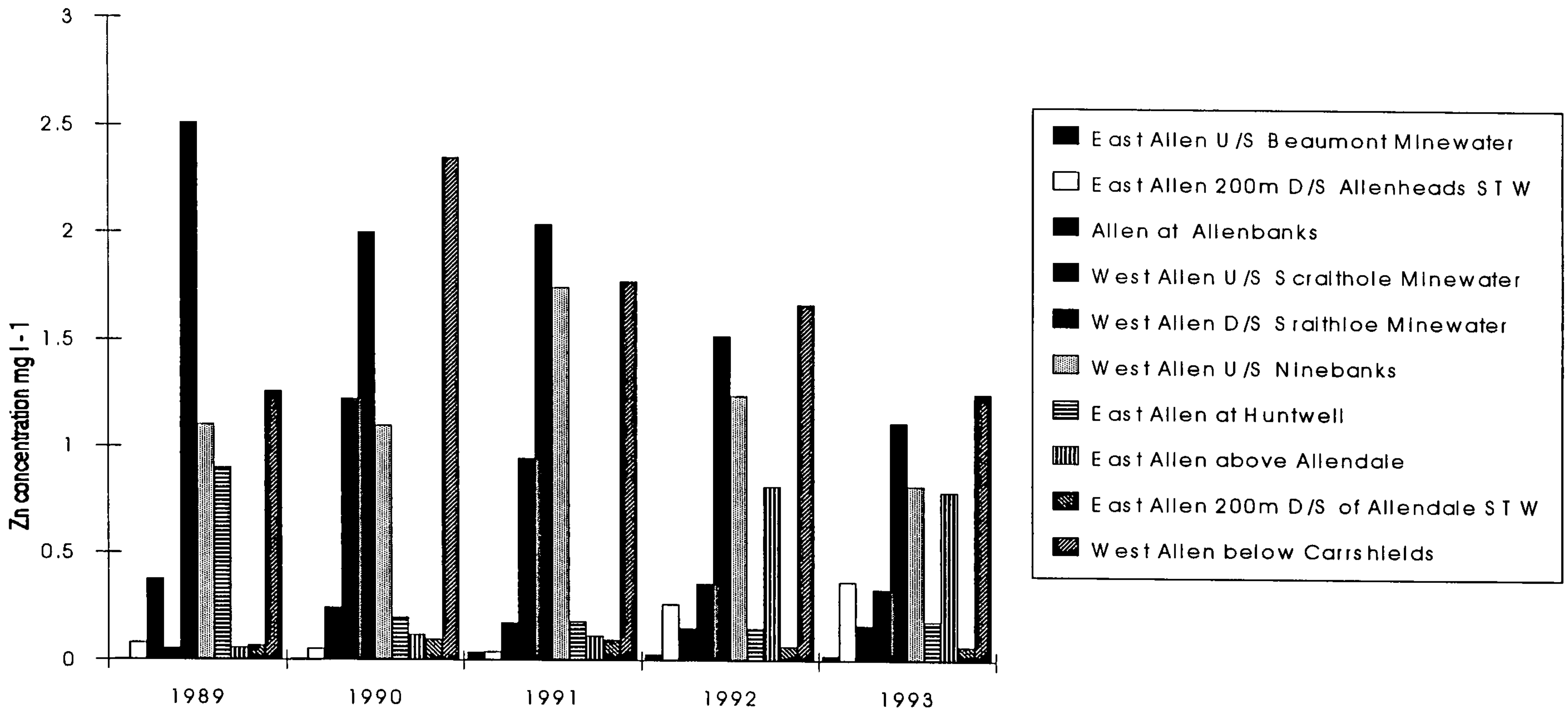


Fig. 6.1(f) The zinc levels of the West and East Allen in 1990 (Data from the NRA)

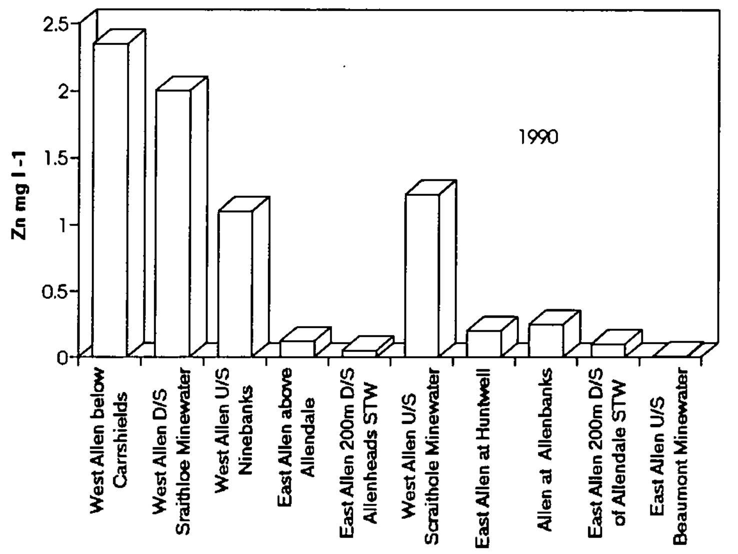


Fig. 6.1(g) The zinc levels of the West and East Allen in 1991 (Data from the NRA)

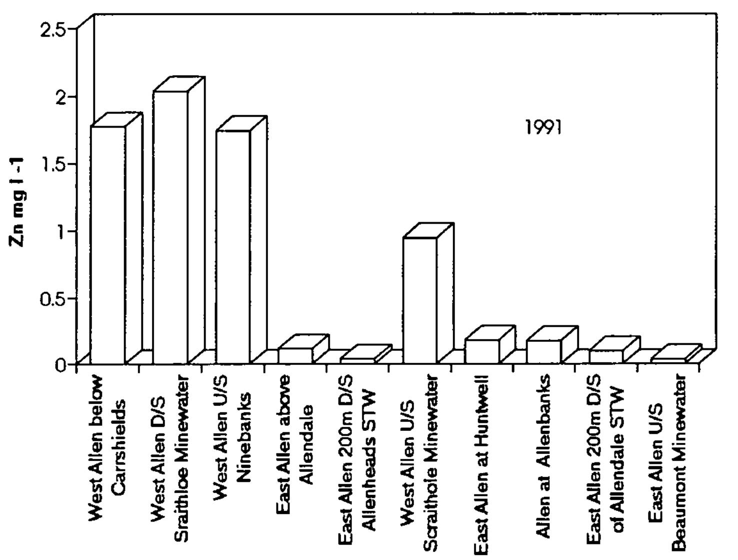


Fig. 6.1(h) The zinc levels of the West and East Allen in 1992
(Data from the NRA)

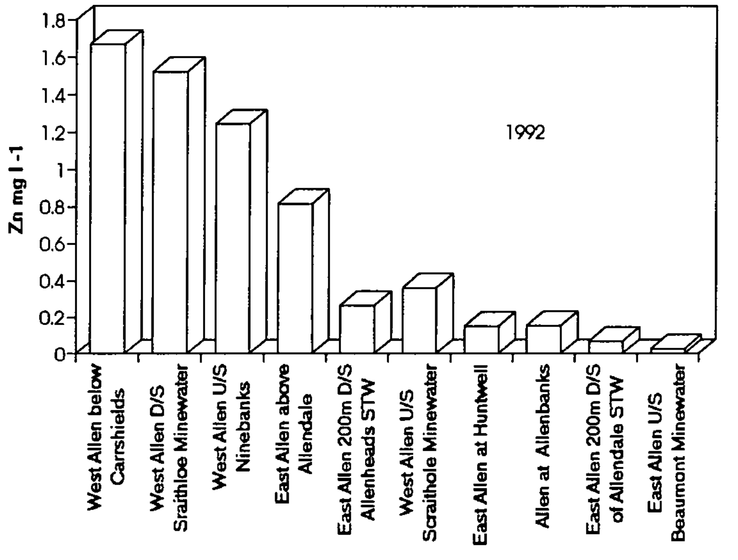
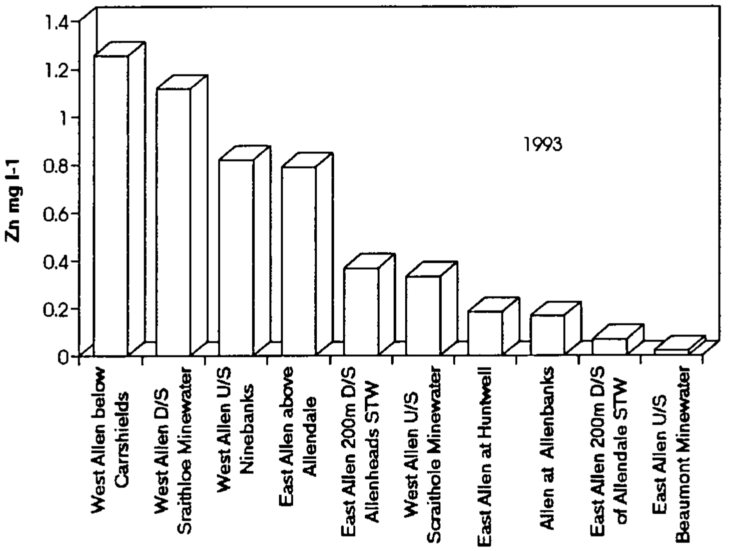


Fig. 6.1(i) The zinc levels of the West and East Allen in 1993
(Data from the NRA)



6.2 Abundance of Invertebrates on the River Allen catchment

The multivariate analysis revealed the differences in the community response to the environmental variables of substrate, depth, width and distance from source. In order to establish the water quality differences between the three rivers the densities of macroinvertebrate fauna were compared. It is generally found that more polluted waterways have a less diverse and less abundant invertebrate fauna. Firstly the numerical differences of invertebrate families was investigated on the broad basis of the River Allen, the West Allen and the East Allen. Then the families of the stoneflies and mayflies were identified to the species level and again the numerical differences compared between the three rivers. In each case the values being compared are the mean number of individuals for each family or species. These are shown for each of the three rivers. The number of sites sampled on the river Allen was six, on the West Allen there were thirteen and on the East there were twelve. The samples were taken at approximately one kilometre intervals. The mean number of individuals of invertebrate families are shown in Table 6.2.1. The mean number of stonefly and mayfly species are shown in Table 6.2.2.

There was a greater diversity of invertebrate families on the East Allen compared to the West. Out of a total of twenty-two families fifteen were present on the West Allen compared to twenty on the East Allen. The River Allen had thirteen of the twenty-two families. The families not present on the West Allen were the Taenidae, Capnidae, Dixidae, Molannidae, Brachycentridae, Lymnephilidae, Ancylidae and Gammaridae. The only families absent from the East Allen were Brachycentridae and Ancylidae. These were only found in very small densities on the River Allen. The families which were found in larger densities on the East Allen were the Taenidae, Capnidae, Nemouridae, Baetidae, Heptegeniidae, Chironomidae, Tipulidae and Hydropsychidae. The was also a greater diversity of mayfly and stonefly species on the East Allen. Out of a total twelve species only eight were recorded on the West Allen whereas eleven were found on the East Allen. The species not present on the West Allen were *Ecdyonurus torrentis*, *Leuctra nigra*, *Diura bicaudata* and *Amphineura sulcicollis*. The only species not present on the East Allen was *Chloroperla tripunctata* which was present on the West Allen. Only eight of the twelve species were recorded on the River Allen. Not found on the River Allen were *Baetis buceratus*, *Ecdyonurus torrentis*, *Leuctra inermis* and *Diura bicaudata*.

Table 6.2.1 The mean numbers of Invertebrate Families from the sites sampled on the River Allens

Taxa	River Allen mean	SE	West Allen mean	SE	East Allen mean	SE
Taenidae	0	-	0	-	0.2	0.15
Leuctridae	0.5	0.22	2.2	0.83	1.4	0.57
Capnidae	0	-	0	-	2.3	0.62
Perlidae	1.3	0.71	2.8	0.72	0.3	0.13
Perlodidae	0	-	3.9	1.74	0.5	0.33
Chloroperlidae	1.8	1.47	6.1	2.11	1.2	0.56
Nemouridae	0.3	0.21	0.4	0.29	1.1	0.54
Baetidae	2.3	1.32	5.6	1.64	14.2	4.55
Heptegeniidae	2.8	3.25	5.9	1.52	17.2	3.56
Simulidae	8.5	0.17	0.1	0.08	0.9	0.69
Dixidae	0	-	0	-	1	0.78
Chironomidae	0.6	0.31	2.6	0.69	3.8	1.66
Tipulidae	0	-	0.2	0.01	0.3	0.24
Dytiscidae	2.7	1.17	5.8	1.3	1.9	0.54
Elmidae	9.2	1.72	0.8	0.47	0.3	0.18
Hydropsychidae	1	0.45	0.1	0.83	1.8	0.52
Leptoceridae	0	-	0.3	0.3	0.1	0.07
Molannidae	0	-	0	-	0.1	0.07
Brachycentridae	0.17	0.17	0	-	0	-
Lymnephilidae	0.17	0.17	0	-	0.1	0.08
Ancylidae	0.17	0.17	0	-	0	-
Gammaridae	0	-	0	-	0.1	0.08
Sums of families	20.5	5.97	36.75	6.07	48.61	7.22

Table 6.2.2 The mean numbers of Invertebrate Species from the sites sampled on the River Allens

Family	Species	River Allen mean	SE	West Allen mean	SE	East Allen mean	SE
Baetis	*Baetis rhodani*	2.8	1.33	2.3	1.71	10.3	3.52
	Baetis buceratus	0	-	0.4	0.37	0.1	0.09
Heptegeniidae	*Rithrogena semicolorata*	4.6	1.32	2.3	1.22	10.6	2.18
	Ecdyuonurus torrentis	0	-	0	-	0.3	0.14
Leuctra	*Leuctra inermis*	0	-	0.4	0.26	0.5	0.28
	Leuctra nigra	0.16	0.15	0	-	0.2	0.18
	Leuctra hippopus	0.3	0.33	0.5	0.26	0.5	0.31
Perlidae	*Isoperla grammatica*	0.3	0.21	1.1	0.47	2.3	0.63
	Diura bicaudata	0	-	0	-	0.1	0.09
Chloroperlidae	*Chloroperlida tripunctata*	0.16	0.17	1.3	0.65	0	-
	Chloroperlida torrentium	1.67	1.12	3.4	2.26	1.3	0.66
Nemouridae	*Amphineura sulcicollis*	0.3	0.21	0	-	0.73	0.19
Sums of Species		10.5	3.44	11.5	4.07	26.81	4.64

6.3 Statistical Analysis of Invertebrate Abundance

To statistically test the abundance of families and species between the three rivers t-tests were used. An F-test: Two-Sample for variances was first performed on the data in order to show if the variances of the samples were equal or not. This determined which t-test to use on the data. The appropriate t-tests were then carried out. The t-test compares the mean number of taxa between two samples or in the present case between two rivers at a time. These revealed which rivers had the greater abundance of each taxa. The data used in the t-test was first log-transformed in order to ensure a normal distribution. Firstly the total sums of invertebrate species and sums of invertebrate families were compared between the three rivers. The significant families and species were then also tested between rivers. The results of the t-test analysis are given in Table 6.3.1.

There were significantly greater densities of invertebrates on the West Allen than on the River Allen (mean of 37 as opposed to 21, $t = -2.05$, $p < 0.05$). There were also significantly greater densities of invertebrates on the East Allen than on the River Allen (49 as opposed to 37, $t = -2.01$, $p < 0.05$). However, no such difference was found between the East Allen and West Allen. Figures 6.3(a)-(c) show the abundance of invertebrates per family on the three rivers, West, East and River Allen respectively. Figure 6.3(d) shows a comparison between the abundance of invertebrates per family on the three rivers.

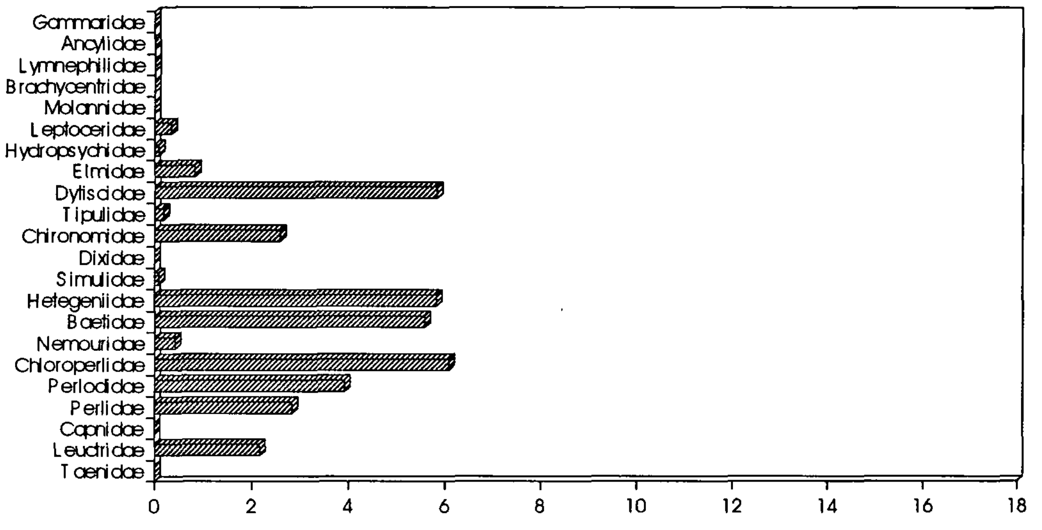
The species and families with the greatest densities were then tested between the rivers. There were significantly greater densities of Heptegeniidae on the East Allen than on the West (17 as opposed to 6, $t = -2.6$, $p < 0.01$) and in particular the species *Rithrogena semicolorata* was more abundant on the East Allen (2 as opposed to 11, $t = -3.53$, $p < 0.01$). This reflects the fact that the Heptegeniidae are less tolerant of pollution and hence the fact that the West Allen suffers from zinc pollution to a greater extent than the East. The more pollution tolerant families Baetidae, Chironomidae and Leuctridae, did not show greater abundance in the East or River Allen as compared to the West, but occurred in almost equal abundance throughout all three rivers. Chloroperlidae and Dytiscidae are also tolerant groups and were found to occur in greater abundance in the polluted West Allen compared to the East Allen (6 as opposed to 1, $t = 2.57$, $p < 0.01$ and 6 as opposed to 2, $t = 2.6$, $p < 0.01$ respectively). Figures 6.3 (e-h) show the abundance of invertebrates per species on the West, East and River Allen respectively. Figure 6.3 (h) is a comparison between the abundance of invertebrates per species on the three rivers.

Table 6.3.1 Results of t-tests: A comparison of the mean abundances of macroinvertebrates on the three rivers.

	River Allen vs West Allen	River Allen vs East Allen	West Allen vs East Allen
FAMILIES			
Sums of Families	-2.15 *	-2.11 *	-0.41
Heptegeniidae	0.56	-1.46	-2.6 *
Baetidae	-0.78	-0.85	-1.29
Dytiscidae	-1.55	0.31	2.6 *
Chironomids	-1 .6	0.97	0.29
Leuctridae	-1.48	-1.07	0.56
Chloroperlidae	-1.62	0.22	2.57*
Degrees of freedom	16	17	23
SPECIES			
Sums of species	-0.13	-1.92	-1.84
Baetis rhodani	0.42	-1.01	-1.43
Rithrogena semicolorata	1.59	-1.68	-3.53 **
C. torrentium	-0.44	0.78	0.83
Degrees of freedom	11	16	17

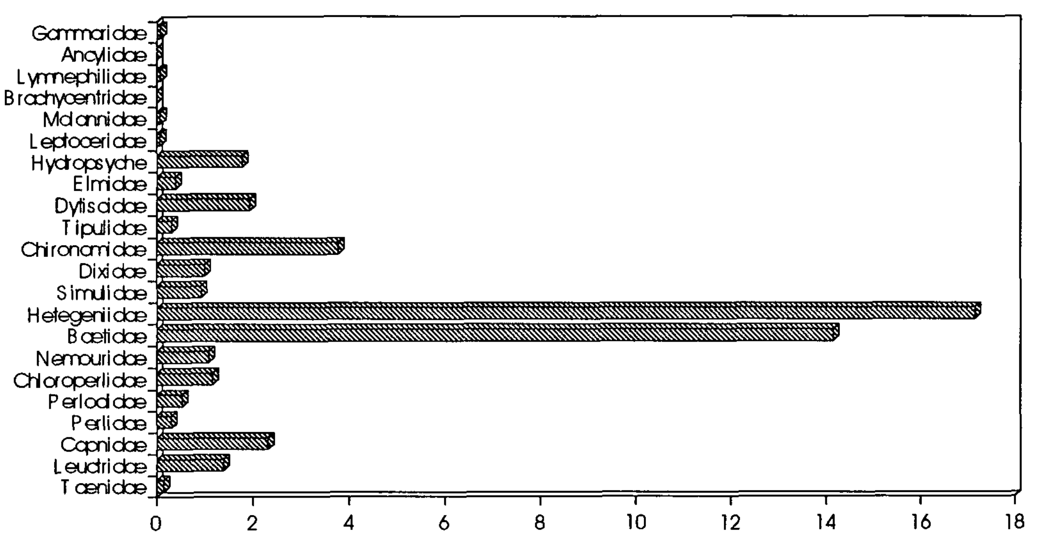
Significance levels $p < 0.05$ * $p < 0.01$ **

6.3(a) The mean number of invertebrate individuals recorded from the sites on the West Allen



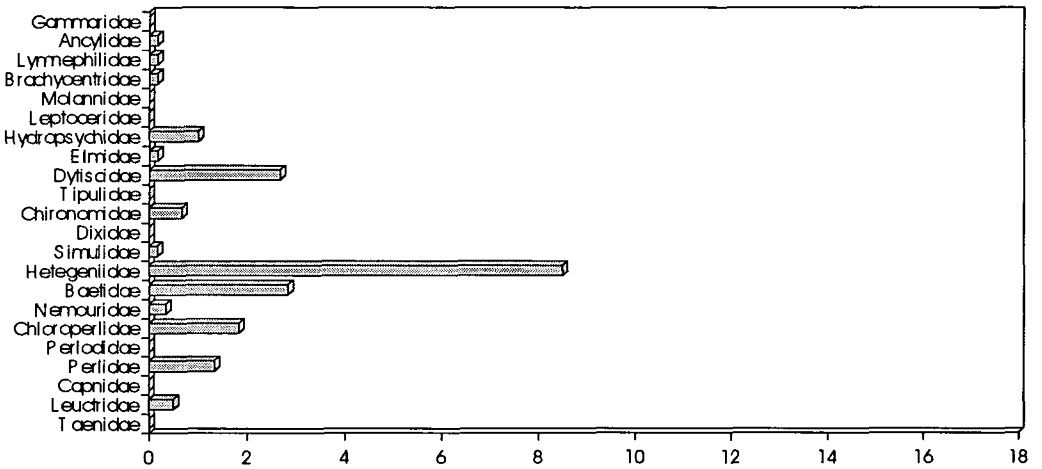
Mean number of individuals per invertebrate family

6.3 (b) The mean number of invertebrate in individuals recorded from the sites sampled on the East Allen



Mean number of individuals per invertebrate family

6.3 (c)The mean number of invertebrate individuals recorded from the sites on the River Allen



Mean number of individuals per invertebrate family

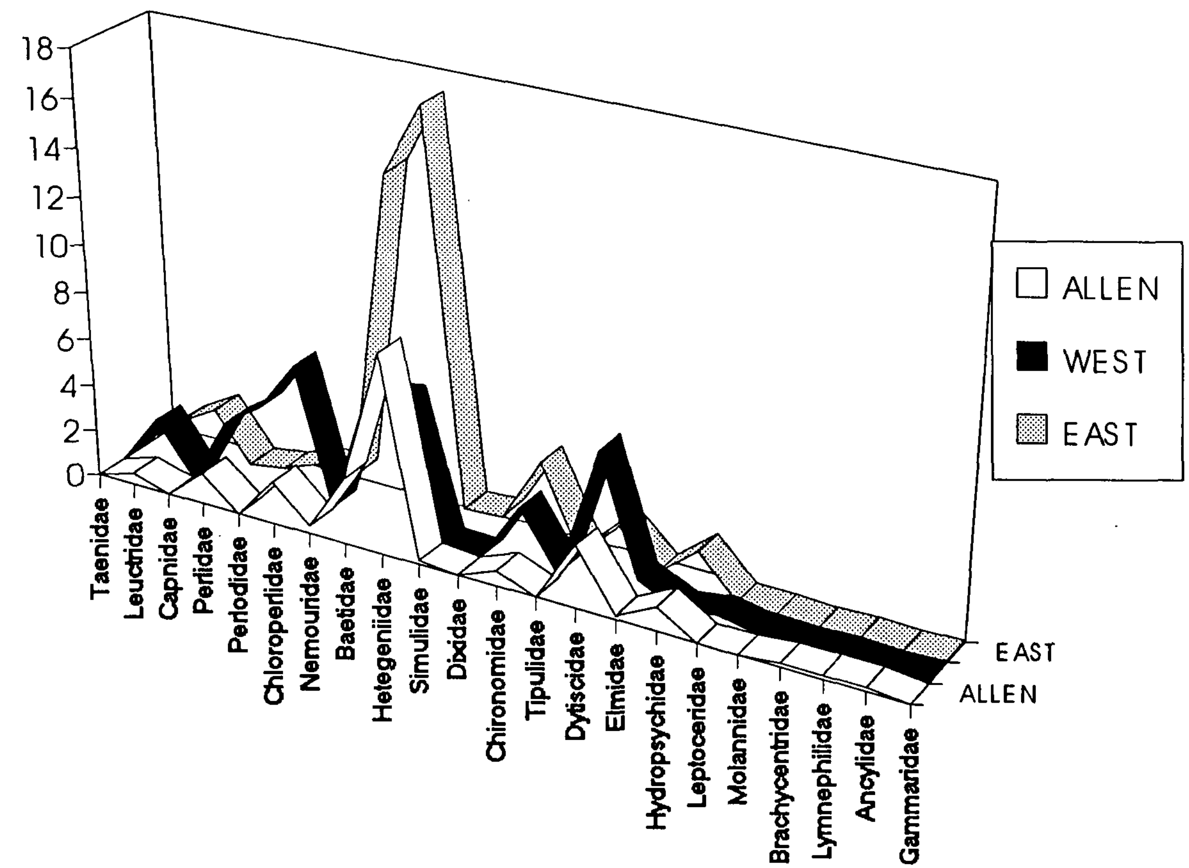
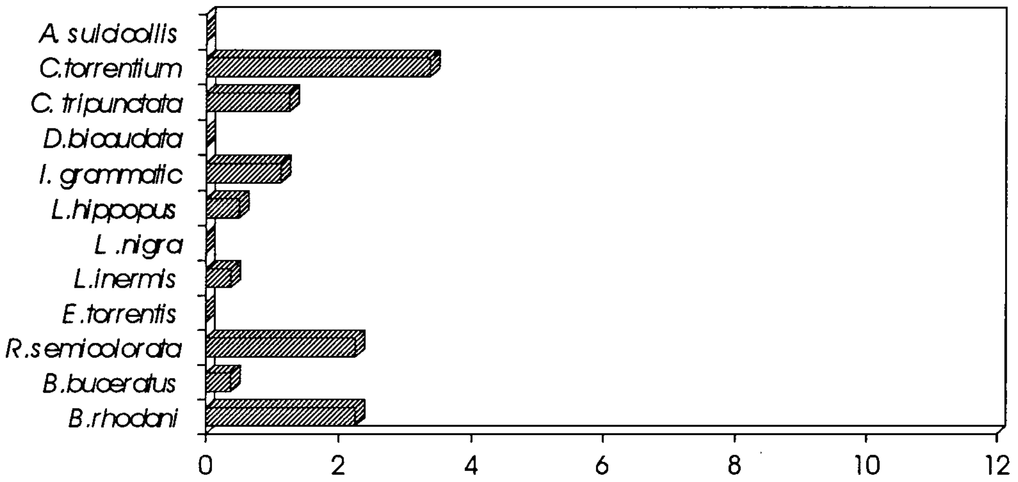


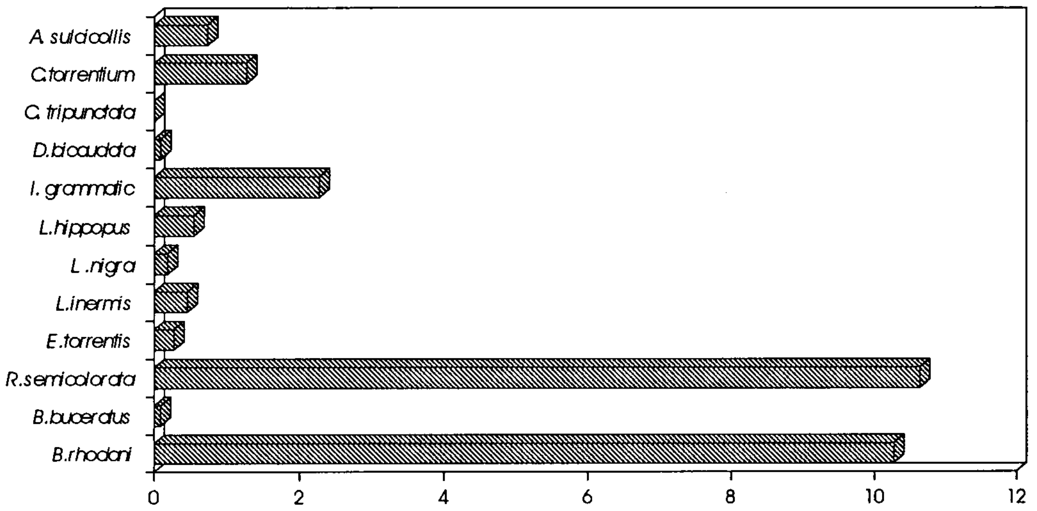
Fig. 6.3(d) A comparison of invertebrate families on the River Allens

6.3 (e)The mean number of invertebrate individuals recorded from the sites on the West Allen



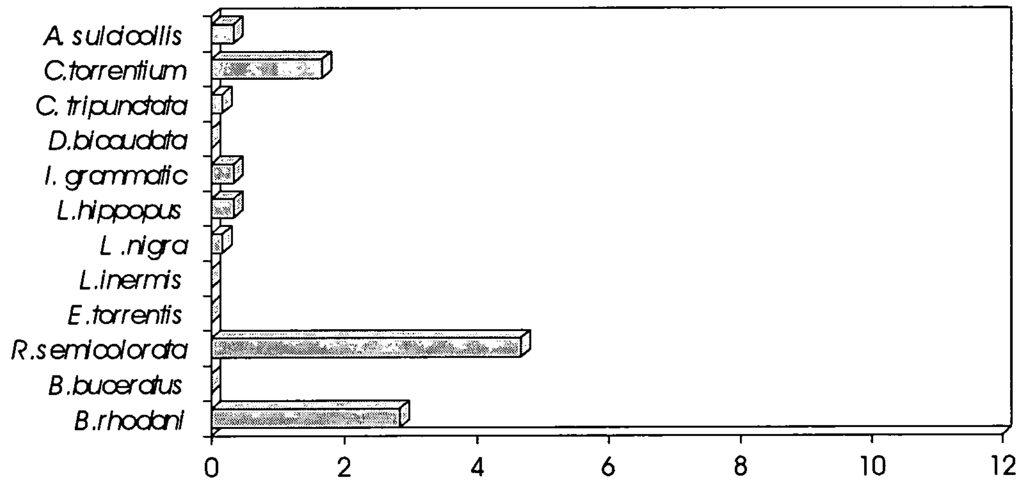
Mean number of individuals per species

6.3 (f) The mean number of invertebrate individuals recorded from the sites on the East Allen



Mean number of individuals per species

6.3 (g) The mean number of invertebrate individuals recorded on the River Allen



Mean number of individuals per species

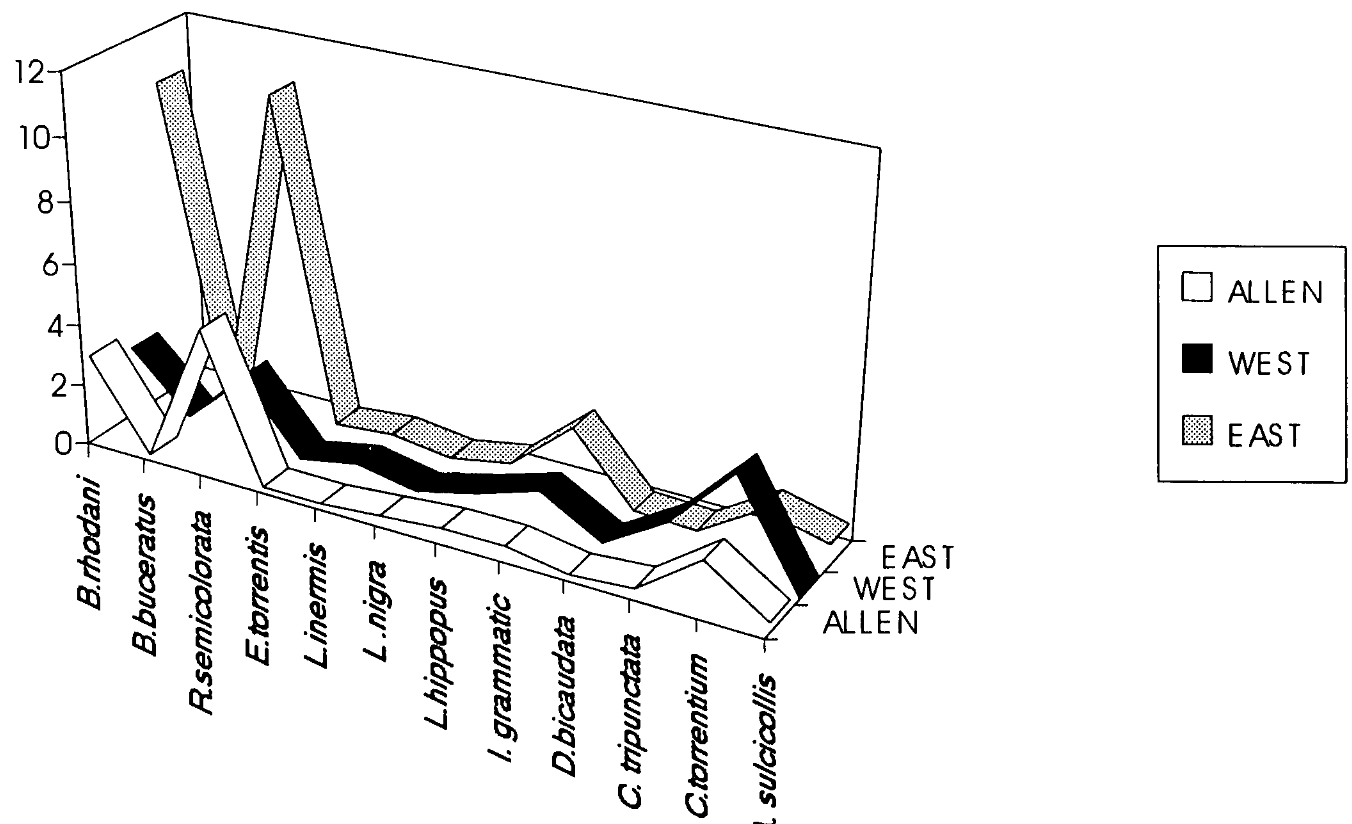


Fig. 6.3 (h) A comparison of the Invertebrate species on the River Allens

7.0 OTTERS

7.1 Habitat Sampling

In order to determine the influence of the habitat variables on the distribution of otters the following indices, adapted from Thom (1991), were used to characterise the River Allen catchment. These were the amount of cover, the level of disturbance, the number of potential holts and lying up places and the total number of mature trees bordering a stretch of river.

1) Amount of Cover:

0) Bare soil/rock
1) Short cut or grazed grass
2) Vegetation to a height of 10 cm - Not dense
3 Vegetation to a height of 10 cm - Dense
4) Vegetation to a height of 50 cm - Not dense
5) Vegetation to a height of 50 cm - Dense
6) Vegetation to 1 metre plus trees and shrubs - Not dense
7) Vegetation to 1 metre plus trees and shrubs - Dense
8) Poorly wooded plus understorey
9) Poorly wooded no understorey
10) Dense shrubs
11) Well wooded
12) Crag

2) Levels of Disturbance

0) No disturbance
1) Occasional disturbance
2) Footpath running alongside - occasionally used
3) Footpath more heavily used by local anglers, dog walkers etc.
4) Very heavily used footpath and river such as in country parks
5) Roads and houses nearby
6) Caravan site adjacent to river
7) River passing through urban areas
8) Heavy industry along banks

3) Number of Potential holts

1) Tree root systems undercut by water to provide ledges and extensive covers
2) Large rock piles
3) Stick piles
4) Holes in the Bank

4) Number of Temporary lying up places

1) Islands of gravel covered with scrub (submerged during spates)
2) Temporary piles of sticks and fallen logs within the river or along the river bank
3) Extensive impenetrable thickets of bankside vegetation

5)The total number of mature bankside trees were also recorded together with the number of saplings. The major trees encountered included the following:

Sycamore (*Acer pesudoplatanus*)
Oak (*Quercus* spp.)
Birch (*Betula* spp.)
Willow (*Salix* spp.)
Alder (*Alnus* spp.)
Ash (*Fraxinus excelsior*)
Elm (*Ulmus* spp.)

These habitat variables were recorded at 100 metre intervals along the East, West and River Allen. Each bankside tree was recorded from the whole length of the river catchment.

7.2 Spraint Collection

Spraints were searched for in and along the river catchment. It was possible to reach prominent boulders within the rivers and hence conduct a thorough search of the watercourse. Other sites searched were under bridges, on fallen logs and prominent piles of earth and sticks. The spraints were carefully scraped into a plastic bag and labelled, with the location and date noted.

7.3 Spraint Analysis

In the laboratory the spraints were prepared for analysis using the following procedure.

The spraints were placed in a labelled petri dish and weighed. They were then dried at 40°C for a minimum of 24 hours, after which time they were weighed again. The dried spraint was then added to a dilute detergent solution. The spraint was allowed to soak for 24 hours. The material was then gently washed through a flour sieve which had a finer sieve placed beneath to catch any material falling through.

The fish bones thus prepared were then identified to the family or species level using, 'A Guide to the Identification of Prey Remains in Otter Spraint' (Conroy *et al.*, 1993).

8.0 <u>OTTER RESULTS</u>

8.1 <u>Otter Habitat Analysis</u>

Evidence of otters, in the form of spraints, was found mainly on the River Allen. Of a total of fifteen spraints, thirteen were found on the River Allen and two on the East Allen. No spraints were found on the West Allen.

Habitat data were collected from sampling sites at 1km intervals along the entire river catchment. The data was then analysed using the multivariate technique of Principle Components Analysis. Principle components analysis reduces an array of correlation coefficients to a smaller set of factors which summarise the observed inter-relations in the data. This shows if there is a significant relationship between the density of spraints and important habitat variables. Due to the small number of spraints collected in the survey the factor loadings relating to otter spraints were very low and not considered significant. Only trends can be distinguished in the importance of habitat variables to otters. The results are presented in the Table 8.1.1. The trends reveal that alder and oak trees and potential holts are the most important factors relating to the distribution of spraint.

Correlation coefficients of the habitat variables in relation to where the spraints were found were also calculated. Again because of the small sample size these must be treated with caution. However, a clearer picture emerges whereby potential holts, lying up places, mature oak and alder trees are significantly correlated with spraint distribution. These are shown in the Table 8.1.2.

Table 8.1.1
Factor loadings relating to otter spraints
(Principle components analysis)

Variable	Spraint
Spraint	0.42
Alder	0.26
Oak	0.19
Potential Holts	0.16
Depth	0.09
Lying up	0.06
Other trees	0.05
Willow	0.01
Cover	0.05
Birch	0.05
Disturbance	0.03
Elm	0.004
Width	0.003
Saplings	-0.003

Table 8.1.2
Correlation coefficients, *r*, between otter spraints and habitat variables

Spraint	**Correlation Coefficient with Spraints**
Spraint	1.00
Alder	0.53**
Potential holts	0.38*
Lying up places	0.36*
Oak	0.35*
Cover	0.29
Depth	0.23
Other	-0.19
Disturbance	0.18
Sycamore	0.15
Width	0.14
Willow	0.11
Birch	-0.01
Elm	-0.04
Saplings	0.03

* Significant at 5% level/ ** Significant at 1% level
Degrees of freedom = 35

8.2 A comparison of the distribution of habitat variables between the East and West Allen.

The River Allen survey found evidence of otters, both spraints and tracks, along the River Allen and into the East Allen, six kilometres upstream from where the East joins the Allen. However no sites or signs were found on the equivalent stretch of the West Allen. For this reason it was decided to compare the habitat variables of the two equivalent stretches of the East and West Allen using a Chi-squared (χ^2) test of distribution. It was necessary to use a non-parametric scaling test in order to avoid the assumptions that the data were normally distributed. Thus a Median test was first performed on the data to test whether the two independent groups differ in central tendencies. The results from this test can then be used in the Chi-squared test in the normal manner. The Chi-squared was used to determine the significance of the differences in the median distribution of habitat variables between the two independent groups. The two independent groups were the distribution of the habitat variables recorded from the last six kilometres of the East and West Allen.

The results are shown in Table 8.2.1. There was more cover of a dense nature found on the East Allen but disturbance levels were also higher on the East Allen. Also higher on the East Allen was the distribution of potential holts, lying-up places and the number of mature oak trees. On average the East Allen was deeper than the West Allen.

The Figures 8.2 (a-F) show a comparison of the median distribution of the habitat variables of cover, disturbance, potential holts, lying up places, mature oak trees and depth along the last six kilometres of the Rivers West and East Allen before they join the main River Allen. The figures are divided into 1km stretches for clarity but the statistical analysis was actually performed on stretches of six kilometres.

Table 8.2.1
The results of the chi-squared analysis showing the distribution differences of habitat variables between the last six kilometres of the East and West Allen

Variable	Chi-squared value
Potential holts	9.32**
Disturbance	8.36**
Depth	7.81**
Cover	3.97*
Lying up places	3.85*
Oak	3.93*
Width	3.41
Alder	2.05
Sycamore	1.57
Willow	0.98
Birch	0.75
Saplings	0.68
Elm	0.09
Other trees	0.04

* Significant at 5% level/ ** Significant at 1% level
Degrees of freedom = 1

Fig 8.2 (a) A comparison of the median cover type as recorded using the cover index on the last six kilometres of the West and East Allen

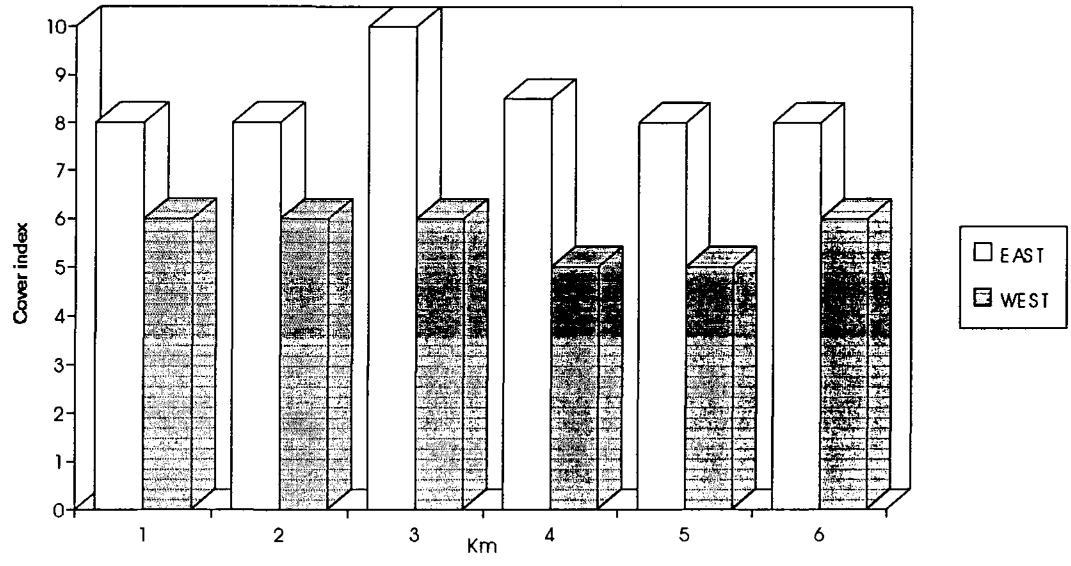


Fig. 8.2 (b) A comparison of the median disturbance levels as recorded on the disturbance index on the last six kilometres of the West and East Allen

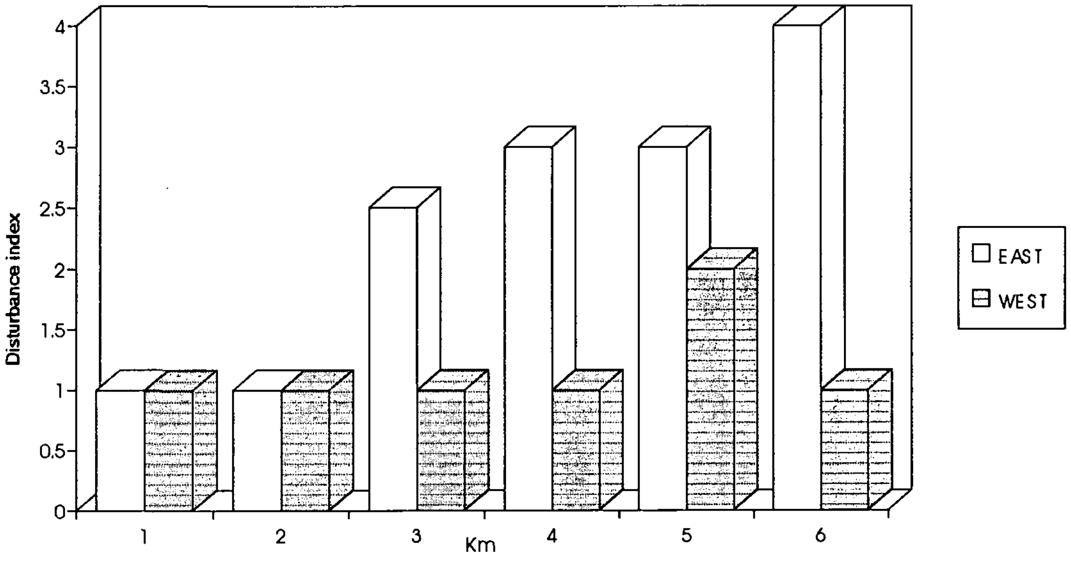


Fig 8.2 (c) A comparison of the median number of potential holts on the last six kilometres of the West and East Allen

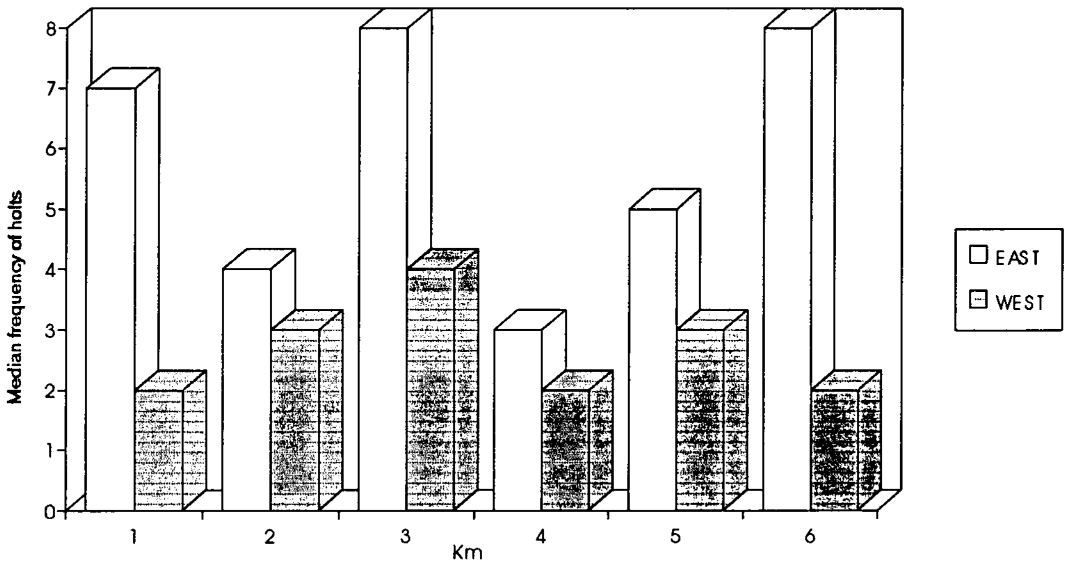


Fig 8.2 (d)A comparison of the median number of lying up places on the last six kilometres of the West and East Allen

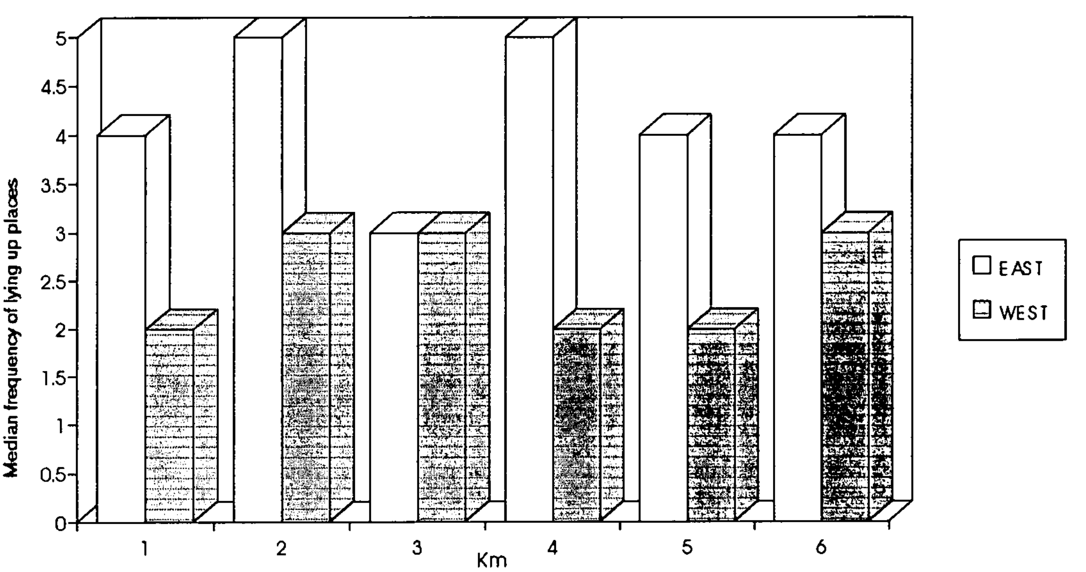


Fig 8.3 (e) A comparison of the median number of oak trees on the last six kilometres of the West and East Allen

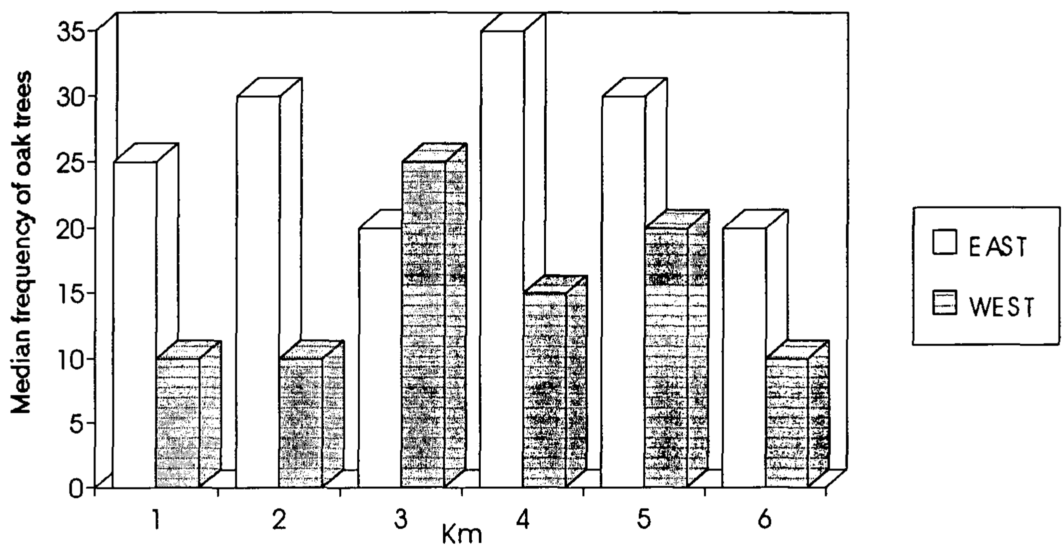
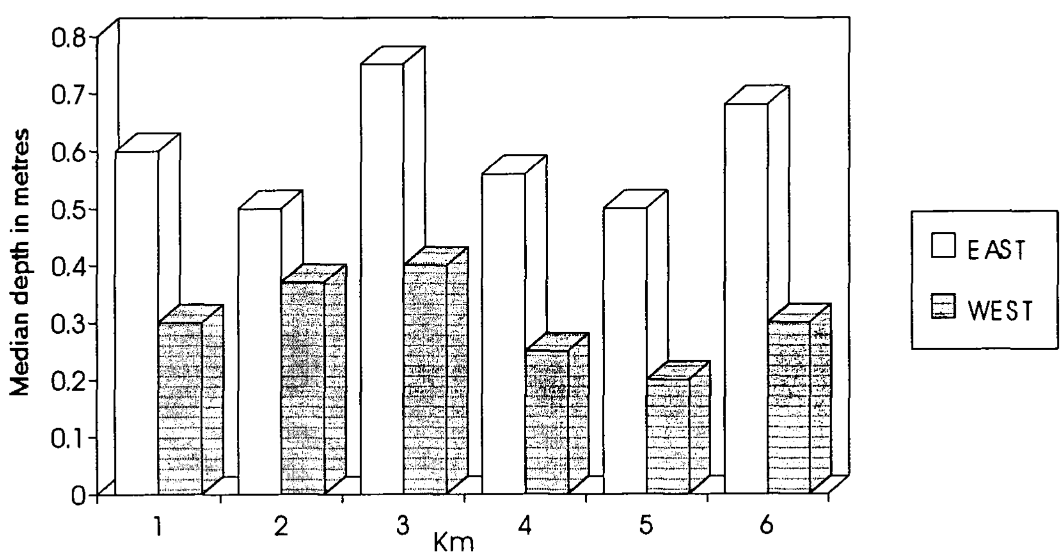


Fig. 8.3 (f) A comparison of the median depth of the last six kilometres of the West and East Allen



8.3 Diet Analysis

A total of fifteen spraints were collected. Only the bones of fish were identified; in most cases to family level but some to species level. Since fish form the bulk of the otters' diet a representation of what the otters were eating can be observed. Five species of fish were identified from the spraints. These were salmonids (*Salmo* spp.) which includes salmon (*S. salmo*) and trout (*S. trutta*); eels (*Anguilla anguilla*); Cyprinidae such as minnow (*Phoxinus phoxinus*); Cobitidae such as stone loach (*Noemacheilus barbatulus*) and perch (*Perca fluviatilis*).

8.3.1 Calculation of Diet from Spraint Analysis

Four methods of presentation of otter diet have been used. The first two relate to the frequency of occurrence of types of fish (Putman 1984). Different fishes have different numbers of bones (Wheeler 1969) and some bones are more prone to breakage (Castel 1976) so inevitably these methods can only give an indication of the otter's diet. Small species may thus be over represented and larger fish with fewer bones under represented in the diet. It is hence impossible to make a direct correlation between the numbers of bones counted in spraints and the number of fish eaten. The remaining two methods estimate the bulk of the prey type in the otter's diet (Wise 1978):

a) Percentage Frequency of Occurrence

This is where all the remains of the same species in a spraint is taken to represent just one specimen. It's frequency is then calculated as the number of times it has appeared in all the spraints collected. The following equation is used:

$$\frac{\text{Number of spraints containing a particular prey item}}{\text{Total number of spraints in the sample}} \times 100$$

b) Percentage of spraint containing a particular prey item

Here all the bones in a spraint are used to calculate the relative frequency for each species in that spraint. Then the relative frequency for the whole sample is calculated as:

$$\frac{\text{Number of occurrences of a prey item in a spraint}}{\text{Total number of all prey items identified in that spraint}} \times 100$$

c)Relative Estimated Bulk

The relative importance of each prey type in a spraint is scored on a scale of 1-10 where 1 is a trace item and 10 represents a spraint composed of only one item. The scores are summated for each prey type and the proportion of the total number of spraints is multiplied by 10 (the maximum possible score for each spraint).

$$\frac{\text{Sum score of item A}}{\text{Total number of spraints}} \times 100$$

d)Bulk Estimate

The bulk proportion factor from (c) for each prey type is multiplied by the dry weight. This is then divided by the sum of all prey types and multiplied by the total dry weight of spraints. The value is expressed as a percentage:

$$\frac{\text{Score of item A x dry weight of spraint containing item A}}{\text{Sum score all items x Total dry weight}} \times 100$$

Eel was found to form the major component of the otters' diet on the River Allens and depending on which frequency of occurrence method is used they accounted for between 40 and 79% of all prey taken. The next major component of the diet were the perch, forming between 29 and 57% of the diet, followed by the salmonids with 11-28 %. From the bulk estimate calculations eel formed between 51 and 59% of the bulk of the diet, perch 37-43%, Cobitidae 10-21%, salmonids 6-11% and Cyprinidae 7-14%. The results are presented in Figures 8.3 (a-d).

Fig. 8.3 (a) Percentage frequency of occurrence

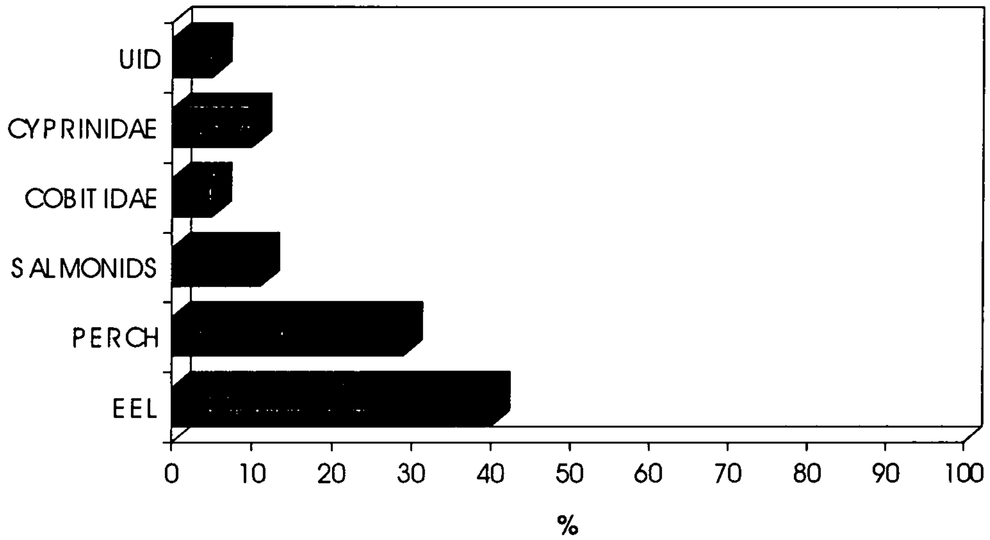


Fig. 8.3 (b) Percentage of spraint containing a particular prey item

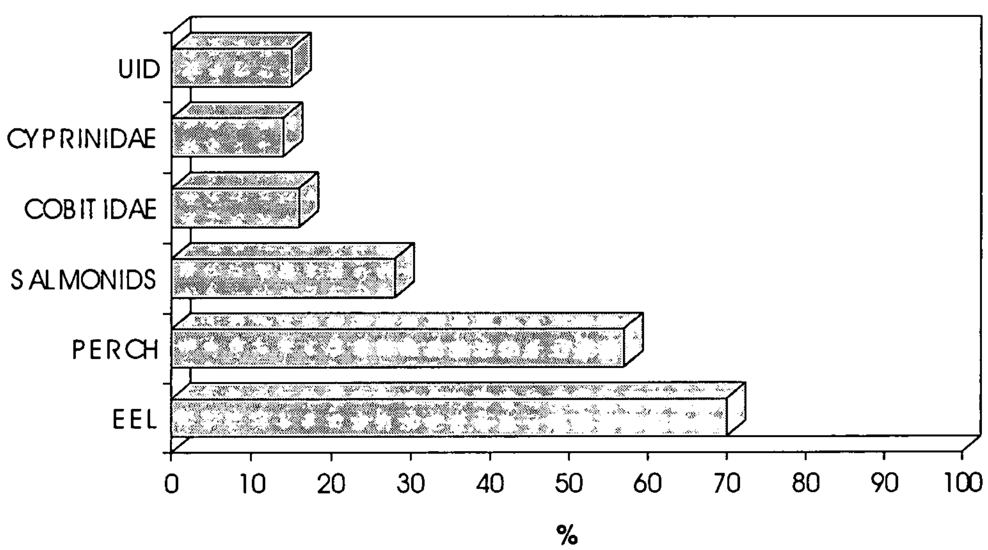


Fig. 8.3 (c) Relative Estimated Bulk

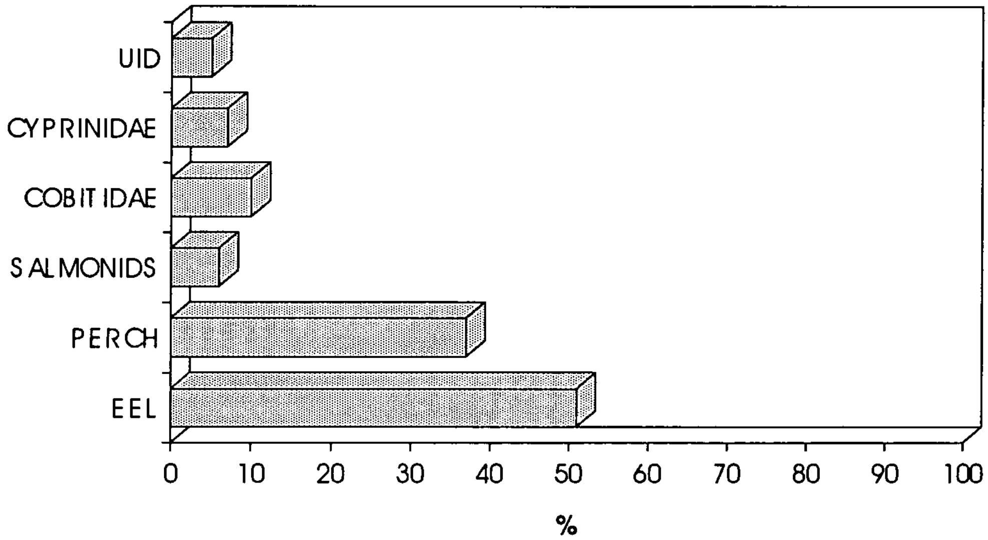
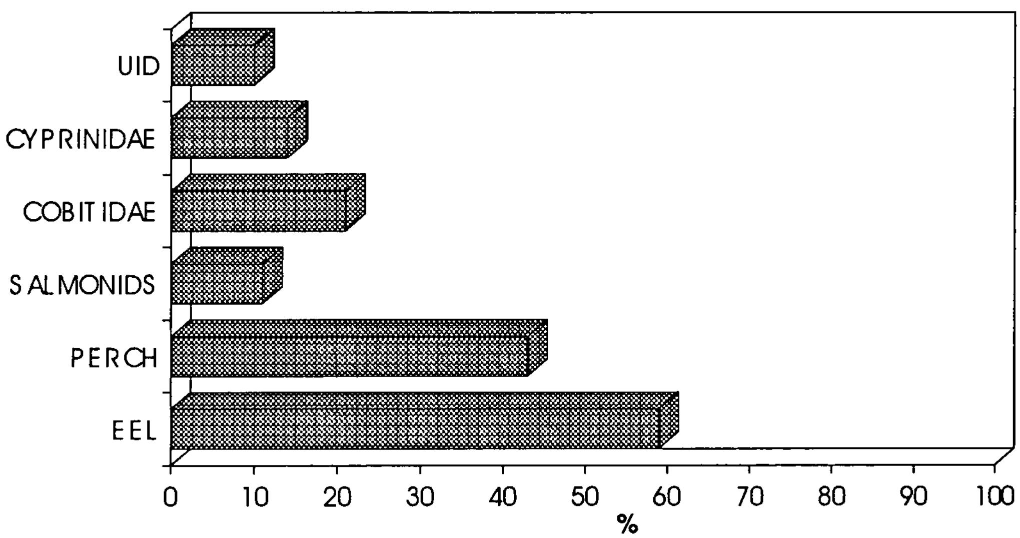


Fig. 8.3 (d) Bulk Estimate



8.4 Size of prey

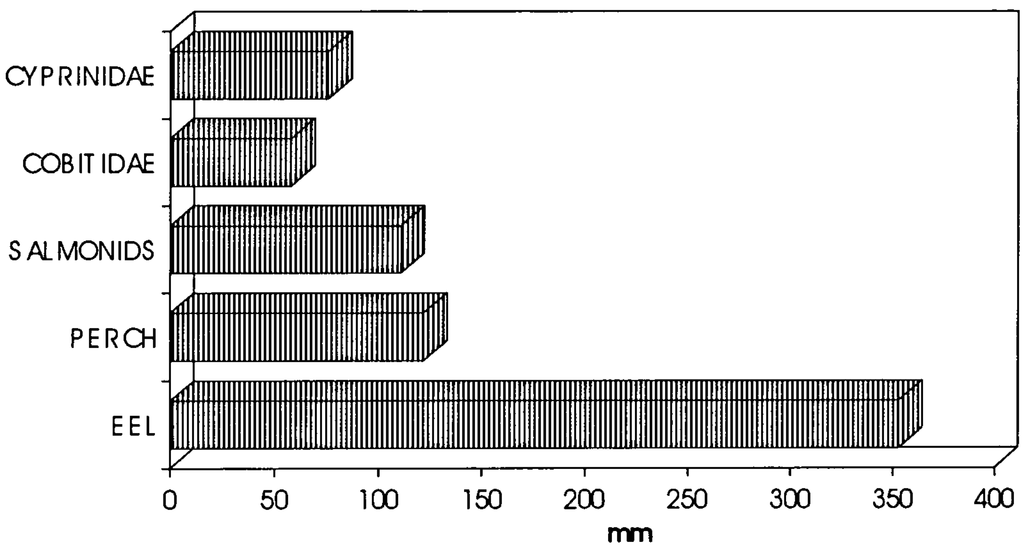
The size of fish taken can be calculated from the relationship between vertebrae size, specifically vertebrae width, and fish length on the basis of equations first described by Wise (1978) and later by (Thom 1990). These can be found in Appendix 1. The anterior caudal vertebrae are those used principally for the identification of fish because they show less variation compared to thoracic vertebrae and also because their fused processes are less prone to breakage. For some prey such as the more important freshwater prey, salmonids and eels, thoracic vertebrae were also used. A comparison of the fish lengths is shown in Table 8.4.1 and Fig 8.4 (a).

The most abundant bones in the spraints were those of eel and perch. The estimated eel lengths varied between 290 and 410mm, perch between 70 and 130mm, Cyprinidae between 70 and 100mm, Cobitidae between 50 and 60mm and salmonids between 100 and 110mm.

Table 8.4.1 The mean lengths and standard errors of the fish identified in the diet analysis

Prey type	Mean length (mm)	Standard error
Cyprinidae	76	63
Cobitidae	58	47
Salmonids	111	102
Perch	122	115
Eel	353	257

Fig. 8.4 (a) The mean lengths of the Fish identified in the diet analysis



9.0 Discussion

Zinc is naturally occurring in the freshwater environment, so that exposure to even a high concentration is one to which species of many groups of aquatic organisms have adapted. The distribution of zinc in natural waters is largely unknown. Nevertheless it is believed that zinc concentrations in natural freshwater systems are probably in the sub-parts-per-billion range. However, due to contamination problems zinc rivals lead as the most difficult element to measure accurately in natural waters (Martin *et al.,* 1980). In apparently uncontaminated streams in northern California Kennedy and Sebetich (1976) measured levels between 0.2 and 0.6 $\mu g\ l^{-1}$. What converts a naturally occurring substance into a pollutant is a marked spread of its presence or increase of its concentration in an environment, usually as a result of human activities. Mines are the most common source of zinc pollution. The problem is that even after centuries of disuse mine dumps may continue to disfigure countrysides and to generate sufficient quantities of toxic heavy metals to render barren adjacent streams or lakes, or at least to change their biotas in characteristically deleterious ways. Ecosystem damage through environmental pollution is real and discernible although the major evidence it yields, visible deleterious change in biotas, tends to be considered less significant than chemical evidence (Weatherly *et al.,* 1980).

Invertebrates

The very considerable tolerance of some aquatic insect species to zinc is indicated by Warnick and Bell (1969). They found that 50% of the mayfly nymphs *Ephemeralla subvaria* survived for 10 days in 16 mg l^{-1} Zn, 50% of the stonefly nymphs *Acroneuria lycorias* survived for 14 days in 32 mg l^{-1} Zn and 50% of the larvae of the trichopteran *Hydropsyche bettoni* survived for 11 days in 32 mg l^{-1} Zn. Nehring (1976) found that the nymphs of the mayfly *Ephemeralla grandis* survived for 14 days in 32 mg l^{-1} Zn.

Zinc is toxic in varying degrees under a range of environmental conditions, such as pH, alkalinity and temperature to various freshwater organisms. Heavy metals are more soluble so more toxic in conditions of low pH. Strong reductions in toxicity with increasing water hardness have been observed for different instars of the larvae of *Chironomous tentans* and copper (Gauss *et al.*, 1985).

The susceptibility of an organism to a pollutant is dependent to quite a large degree on the stage of the life-cycle exposed. In general, immature stages are more sensitive to zinc than adults. The juvenile stages of Chironomidae are clearly separated instars by ecdysis. The 96-h LC_{50} (median lethal concentration for a 96 hour period) for *Chironomous tentans* larvae to copper was between 12 to 27 times higher for first instar compared with the fourth instar (Gauss *et al.*, 1985).

Zinc Pollution and Invertebrate Communities

The inhabitants of eroding substrata streams, such as the Rivers East and West Allen, in the absence of pollution would normally comprise of a rich assortment of worms, leeches, shrimps, insects, mites and molluscs. In comparison to organic pollution zinc causes no distinctive zonation pattern that occurs with decrease of pollutant concentrations with distance from point of discharge (Hynes 1960). Instead a decline in the concentration of zinc in the water has been found to be related to a progressive increase in the number of species and in the number of individuals. A classic study of zinc pollution and freshwater communities was begun by Carpenter (1924). The River Rheidol in southwest Wales was polluted by adjacent lead and zinc mines. Between 1991 and 1922 only chironomid and simulid larvae (Diptera) and ephemeropteran nymphs (*Cloeon*) were collected immediately below the mines. However, from the Lower Rheidol 14 species including Arachnida, Hemiptera, Coleoptera, Plecoptera, Ephemeroptera and Arachnida were collected. During 1922-1923, 29 species were collected. After closure of the mines recovery of the stream biota began firstly with algal bryophyte growth, followed by some of the less tolerant invertebrates, such as Oligochaeta and Platyhelminthes and finally vascular plants became established together with a complete stream invertebrate and vertebrate fauna (Carpenter 1926). A survey during 1931-1932 collected 103 species (Laurie & Jones 1938). Only one species was added to this number, a trichopteran *Glossoma conformis,* when the river was surveyed during 1965-66 (Jones & Howells 1975). The fauna was dominated by Plecoptera, Ephemeroptera, Diptera and Trichoptera.

Active mining has not occurred on the River Allens for at least fifty years. However, the effects of the zinc pollution continue today. To demonstrate the persistence of zinc pollution from old mine workings Jones carried out a survey of the River Ystwyth 35 years after the end of mine operations (1958). The river was still zinc polluted. Only 45 species were collected, the same number as in a survey in 1939-1940. Invertebrate groups still absent were Crustacea, Mollusca and Annelida. In contrast in the nearby unpolluted River Dovey, Jones (1941) collected a rich and varied fauna. Jones concluded that it was in species richness, rather than abundance, that the River Ystwyth was lacking compared to the nearby unpolluted streams.

Detritus was the main food source and was presumably being processed by a smaller number of species than were found in the unpolluted streams but with similar overall efficiency. However, the polluted streams were severely depleted of fish which act as a predatory force of considerable influence on the diversity, distribution and composition of macroinvertebrate communities.

The River Allens still suffer from zinc pollution. The West Allen is the worst affected. In 1993 the zinc levels recorded on the West Allen were actually lower than in the four preceding years. However, on the West Allen the stretch below Carrshields had the highest concentrations of dissolved zinc, averaging 1.20 mg l^{-1} Zn in 1993, followed by the area downstream from Scraithole Minewater, 1.10 mg l^{-1} Zn, and upstream from Ninebanks, 0.82 mg l^{-1} Zn, had the third highest levels. The East Allen has comparatively lower dissolved zinc levels than the West. However, at the sampling site above Allendale and 200m downstream from Allenheads sewage treatment works the zinc levels were uncommonly high in 1993, averaging 0.79 and 0.37 mg l^{-1} Zn respectively. This trend of high zinc levels on the East Allen was also observed in 1992 with levels 2-3 times higher than those recorded in the previous four years. It is therefore not surprising that the differences in invertebrate fauna, and hence water quality, between the West and East Allen found by the present study should not be so acute as it has been in the past, and certainly at the time of Abel & Green's (1981) study of the rivers in 1979-1980.

The present study found that the West Allen was qualitatively and for the most part quantitatively restricted in terms of its invertebrate fauna in comparison to the East Allen. Out of the twenty-two families found in total eight were absent from the West Allen. These were the Taenidae, Capnidae, Dixidae, Molannidae, Brachycentridae, Lymnephilidae, Ancylidae and Gammaridae. In contrast the East Allen was only lacking the two families Brachycentridae and Ancylidae. The results of the River Allen are less clear, with this river lacking the same eight families as the West plus one more, the Perlodidae. Out of the twelve stonefly and mayfly identified to the species level, the West lacked four, namely *Baetis rhodani, Ecdyonurus torrentis, Diura bicaudata and Amphineura sulcicollis.* In contrast the East only lacked *Ecdyonurus torrentis* and *Diura bicaudata.* Again results from the River Allen show it lacked five of the twelve species; *Baetis buceratus, Ecdyonurus torrentis, Diura bicaudata, Leuctra inermis, Ecdyonurus torrentis* and *Diura bicaudata.*

Abel & Green (1981) found that the West Allen had considerably higher levels of dissolved zinc than the East. They found that the West Allen received zinc inputs from mine workings and spoil heaps along its length, particularly between three and six kilometres from the source of the river. On one pair of representative and comparable sites, in terms of their depth, width, distance from source, substrate characteristics and nature of surrounding terrain, the West Allen was found to have an average of 1.31 mg l^{-1} Zn compared to the East Allen's 0.13 mg l^{-1} Zn. The West Allen thus had levels between three and ten times higher than did equivalent sites on the East Allen. The dissolved zinc levels of the West Allen in 1981 are comparable with those present in 1993, but the present study found some zinc levels in the East Allen of up to 0.79 mg l^{-1} Zn, although the lowest recorded dissolved zinc levels on the East Allen were 0.02 compared to 0.3 mg l^{-1} Zn on the West Allen in 1993. In 1981 the two rivers were similar in terms of pH, conductivity and concentrations of alkali metals and most of the heavy metals within the detection limits of the analytical methods employed. In 1993 data received from the NRA showed there were no significant differences in pH, conductivity, dissolved oxygen and nitrate and nitrite levels between the West and East Allen.

To determine the lethal toxicity of dissolved zinc to invertebrate species, the following species: *Gammaridae pulex, Baetis rhodani, Rithrogena semicolorata, Chloroperla torrentium, Leuctra* sp. and *Limnephilus* sp., were collected from unpolluted streams and exposed to a range of zinc concentrations in a dilution of similar chemical quality to that of the West Allen (Abel & Green 1981). The sublethal effect of zinc on the feeding behaviour of *Limnephilus* larvae was also tested. Zinc concentrations comparable to those recorded on the West Allen caused a reduction in feeding rate of 10 - 30%. The ability of *Gammaridae pulex* to detect and avoid zinc in solution was investigated using a choice chamber. *G. pulex* was found to detect and avoid zinc in the laboratory at concentrations of 1 mg l^{-1}. Thus the amount of zinc in the West Allen would clearly influence the distribution of the invertebrate fauna.

Abel & Green (1981) found a total of seventy-two species on the East Allen, compared with only twenty-two in the present study. However, the method of collection was different; they used an 0.1 m^2 Surber sampler and sampled for a longer period; at monthly intervals for a period of eighteen months. An evaluation of the kick-sampling technique by Frost *et al.,* (1971) considered the variations between samples of equal size, the effect of sample size, the result of the repeated sampling of the same size, the effectiveness of the technique for removing animals from the stone surfaces and various parameters for the loss of animals from the net. Small samples were found to have consistent percentage population components differing significantly from large ones. Even when the benthos is numerous less than 20% is taken, including less than

5% of the truly lithophilic species. Kicking was an effective method of collection in that almost 60% was taken at the first kick and three kicks yielded 90% of the organisms secured by ten. Some animals were able to escape from the net, bypass it or pass through it and the normal drift could make a significant contribution. The Surber sampler (Surber 1937, Macan 1958) is a combined net and sampling quadrat. The sampler enables quantitative estimates to be made of faunal density but its use is restricted to running water shallower than a metre and where the substrate is not composed of large stones and boulders. Thus the main differences between the two techniques is that the Surber provides a more accurate quantitative measure but this can be achieved by kick-sampling if the collection is over a fixed time period.

Out of the twelve most common taxa recovered by Abel and Green (1981), eight were also common in the present study. These were *Leuctra* sp., *Amphineura sulcicollis, Chloroperla* sp., *Isoperla grammatica, Baetis rhodani, Rithrogena semicolorata,* Chironomidae and Gammaridae. Of these twelve the taxa not recorded in the present study were *Perlodes microcephala,* Limnephilidae, *Polycentropus flavomaculatus* and *Rhyacophila dorsalis.* Of the twelve most abundant taxa, *Gammaridae pulex* and Limnephilidae, were absent from the West Allen. Similarly no *Gammaridae* were found in the West Allen in the present investigation. The larvae of *Baetis rhodani* and *Rithrogena semicolorata,* did not occur after May. In contrast the present study was conducted during June and both these Ephemeropteran larvae were present in both the West, East and River Allen. The authors concluded that the invertebrate fauna of the West Allen is qualitatively and quantitatively restricted in comparison with the physically similar East Allen which contains lower levels of zinc. Although the present study can draw similar conclusions the differences of the invertebrate fauna of the two rivers were not so clear cut and this can probably be attributed to the much less distinct zinc levels of the two rivers at the time of the present study and also to the more restricted sampling. Another significant factor was that at the time of invertebrate sampling the river was in spate so the data collected was some way from the normal state of affairs. How much this influenced the results is difficult to say for certain, but it must be taken into consideration when conclusions are being drawn.

In Abel & Green's (1981) study *Rithrogena semicolorata* was absent from a number of sites of the West Allen even though zinc at concentrations up to 100 mg l^{-1} failed to cause mortality over an exposure period of two weeks. Although apparently resistant to dissolved zinc in these lethal toxicity tests, the distribution of these larvae may be affected by the sublethal effects of zinc. The present study found *Rithrogena* *semicolorata* at most of the West Allen sites but it did seem to be more abundant in the lower reaches where zinc levels were correspondingly lower.

G. pulex was found to detect and avoid zinc in the laboratory at concentrations of 1 mg l^{-1}. It would be useful to see if other species can react in the sane manner. Thus the absence of animals from certain polluted areas may be the result of avoidance behaviour. Increased levels of swimming activity have been observed to be associated with avoidance reactions. This may have some effect on the ability of invertebrates to influence their position in the stream. They could in this way increase the rate of downstream drift and hence influence the population densities in polluted stretches.

The West Allen is more severely polluted than the adjacent East Allen. This can be seen in the restricted abundance and diversity of its macroinvertebrate fauna compared to that of the East Allen. These high zinc levels may be inflicting lethal and sublethal effects on the fauna and have consequences throughout the aquatic ecosystem. For instance the removal of the less tolerant species may result in alterations in the trophic and biotic interrelationships. Thus the heavy metal pollution may also be affecting the primary producer and decomposer levels of the biota thus affecting the overall productivity of the river (Hellawell 1986). It remains to be investigated whether the presence of other heavy metals occur in sufficiently high quantities to have an effect on the ecosystem. Zinc is rarely, if ever, alone as a pollutant. Copper, markedly synergistic with zinc in its action on organisms, frequently occurs with zinc in the same ore body and is released by similar biogeochemical processes. Various other metals that coexist with zinc are also synergistic in their actions.

Toxicity of Zinc

Fish and Otters

How does the zinc pollution affect the otters? Otters are more piscivorous than mink which will take a wider range of food items. The main bulk of an otter's diet consists of fish. What effect then will the zinc polluted waters have on the fish populations on the River Allens and will this in turn have any effect on the otter's distribution? Melquist and Hornocker (1983) found that food was the most important factor determining the distribution of the river otter *L. candensis*, but that radio tagged otters would avoid areas of good prey availability if cover and the number of resting sites was low.

The presence of zinc in freshwater other than at the trace amounts associated with background levels has long been known to have toxic effects of varying intensities on fish populations. Zinc can reach fish trophically through the food chain. Changes in concentrations of zinc in tissues of brown trout (*Salmo trutta*) took place only when the fish was feeding emphasising the importance of the food supply as a source of heavy metals (O'Grady & Abdullah 1985). The mechanism by which zinc toxicity actually kills the fish is thought to be direct damage to the gill membranes. Structural damage results and the fish die with symptom very like hypoxia (Weatherley *et al.,* 1975). Chronic affects are just as hazardous to fish populations as the acutely toxic effects. Crandall and Goodnight (1963) demonstrated that sustained exposure to zinc sulphate produced 'stress' which was manifested in poorly developed vital organs of newborn guppies (*Lebistes reticulatus*).

The effects of zinc on fish are modified by concentrations of zinc and time of exposure. They are further modified by environmental factors. As for plants and invertebrates the major factors affecting the toxicity of metals to fish are pH, hardness and oxygen and these are also the factors which often affect metal accumulation. Low pH is associated with high toxicity; alkalinity: toxicity of zinc is inversely related to alkalinity (Lloyd 1960, Skidmore 1965); and oxygen: zinc toxicity and oxygen are inversely related (Skidmore 1965). These factors together with the influences of species, age/stage in life-cycle, temperature and behaviour must be considered when assessing the toxic effects of dissolved zinc on wild fish populations (Skidmore 1974).

Salmonids indicate clean and not solute-rich conditions. Where there are only a few sparse species of coarse fish, such as bream and eel, pollution is probable. In general, non-salmonid species are more resistant to zinc than salmonids (Haslam 1990). Within fish communities there can be marked interspecific differences in zinc tolerance. Bream, roach and perch are 4-5 times more tolerant of zinc than is rainbow trout (Ball 1967). Even among closely related species, differences may be considerable. The zinc tolerances of four salmonid species were in the following order: brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), cutthroat trout (*Salmo clarki*) and rainbow trout (*Salmo gairdneri*) (Nehring & Goettl 1974)

Many studies have stressed the major effects of heavy metals on the reproduction and fecundity at concentrations well below the accepted LC_{50}. Zebrafish

(*Brachydanio rerio*) were exposed to the highest sublethal dose of zinc during the period in which the gametes were maturing (Speranza *et al.*, 1977). Spawning was delayed and the number of eggs produced was reduced to 38% of the controls and only 21% of these were viable compared to 90% of the controls. In addition the survival rate of the progeny was only 0.9% compared to 63% of the controls. The male of the vivparous guppy (*Lebistes reticulatus*) exhibited reduction in spermatogonia, spermatids and sperm whilst females showed reductions in mature oocytes (Sehgal & Saxena 1986).

Temperature is an important factor influencing zinc toxicity. Survival times tend to shorter at higher temperatures (Herbert 1962). Temperature has quite complex effects. For example, above 15° C survival of salmonids is curtailed but at lower temperatures (about 5° C) the lethal threshold value is reduced and therefore toxicity increases. Hodson and Sprague (1975) concluded that, in polluted rivers, zinc concentrations would be more damaging to fish in the winter months. In unacclimated fish, lower dissolved oxygen concentrations reduce survival while organic material can absorb zinc and hence enhances survival.

Probably the most important factor in the effects of zinc on the fish population from the otter's point of view is the behavioural response. Many fish have been found to exhibit avoidance behaviour at very low levels of zinc concentrations. Sprague (1968) found that rainbow trout were able to detect and avoid sublethal concentrations of zinc sulphate of 5.6 $\mu g\ l^{-1}$, which is 1% of the lethal threshold concentration of 570 $\mu g\ l^{-1}$. Sprague *et al.,* (1965) found the threshold avoidance level for Atlantic salmon (*Salmo salar*) to zinc to be eleven times (53 $\mu g\ l^{-1}$) higher than for rainbow trout. Sprague *et al.,* (1965) noted that these values obtained in the laboratory are necessarily minimal because under field conditions, the natural behaviours of spawning, migration and territoriality, may produce an overriding motivation for the fish to remain within a zinc-polluted environment. Hence it would appear that the fish can sense zinc concentrations greater than background, be they lethal or sublethal, and this will profoundly effect their population dynamics. For instance avoidance of zinc polluted waters may cause fish to leave polluted waterways and prevent their return into a potentially useful environment such as an unpolluted spawning ground. This was dramatically demonstrated in Atlantic salmon whose behavioural response to zinc and copper polluted river system resulted in serious depletion of spawning stock (Sprague *et al.,* 1965).

The evidence for bioaccumulation of zinc by fish is scanty. There are three sources by which zinc might enter fish: the water, (Brown & Chow 1977), the sediments ingested along with benthic food sources, (Bradley 1977), and via the trophic route (Bradley 1977). However, even when it does occur it does not usually appear to be the cause of death. From Windom *et al.*'s (1973) study on marine fish one might expect that fish at the end of long food chains to show greater tendency to accumulate zinc than members of the same species in unpolluted environments. Fish may thus contain dangerously high levels of heavy metals (Chanin 1985). Otters feed at the top of the food chain, so inevitably will ingest the highest dose of the polluting substances. The otter has no way of knowing if a fish is affected or not. No doubt what is poisonous to the fish will be poisonous to the otter. Thus on the River Allens the otters are not only faced with a depleted food supply, but what fish there are may also be contaminated with harmful levels of zinc.

Otter Habitat Survey

A total of fifteen spraints were collected over the survey period. This small sample size is a reasonable number for otters at low density. However, it could also be accounted for by the fact that at the time of the survey weather conditions were inclement. Heavy rains meant the river was in spate. Since spraints are normally deposited on boulders in or nearby the water, under bridges and other prominent places the river flooding can easily wash them away. Indeed, Kruuk, (1992), looking at the distribution of spraint in Shetland found that more than 30% of spraints were deposited in places that flooded within hours, and so the spraints were only functional for a short period of time. Hence under these unusual conditions, and with the time period involved, it was not possible to enlarge the sample size.

In the present study spraints were initially used as an indicator of the presence and distribution of the otters along the River Allen catchment. However, it was then attempted to use the density of spraint as an indicator of important habitat variables. This technique has been strongly disputed (Kruuk *et al.,* 1986). Kruuk looked at the habitat utilisation by otters of the Shetland coast. He divided the area into blocks and then measured the amount of activity of the otters in each block. He found that spraints were associated with the presence of otter holts and certain habitat features. However, he argued that there was no correlation between the intensity of sprainting and the frequency of use of an area by the otters. However, since sprainting is likely also to serve as a form of communication it will not be a function of activity alone. He concluded that in order to make valid comparisons between otter populations the habitats involved should be of a comparable nature in terms of their vegetation and physiography. The stretches of river surveyed should also be long, at least 5km, and seasonal variations in sprainting activity must be taken into consideration.

Support for the use of spraint density as a measure of population status comes from Mason and Macdonald (1987). In an intensive survey of the Mediterranean basin they found a positive correlation between the mean number of spraints and the percentage of positive sites. However, there is an element of circularity in this argument since the positive sites were classified by the presence of spraint. Nevertheless the presence of spraints can be used with most certainty to indicate population status.

A large body of support exists for the relationship between spraint density and habitat utilisation. Macdonald, Mason & Coghill (1978) examined a small and fragmented population of otters on the River Teme in the West Midlands of England. They thought that the otters occurred in stretches where there was more bankside vegetation, more potential holts (sites for lying up and/or breeding), and a greater density of bankside trees, especially ash and sycamore. However, the authors did not provide statistical evidence to support this observation. What their study did show was that there were more potential holt sites, in the roots of ash and sycamore, on stretches of river where otters were present than on the stretches from which otters were absent.

Bas *et. al.,* (1984) studied the vegetation types on the banks of the River Dee during three summer months on the assumption that the densities of spraints give an index of otter activity. A consistent pattern emerged whereby more spraints were found on river banks with a dense vegetation with fringes of trees. This was not only within the 0-5m range from the river's edge but as far back as 50m.

Macdonald and Mason (1985) surveyed 1000m of waterways at 52 sites searching for signs of otters in north-east Greece. The habitat was assessed for the suitability to otters. Sprainting intensity was correlated with the amount of cover. In upland rivers *Rubus* was especially important to otters, with *Salix* scrub being important on both upland and lowland rivers and *Phragmites* on canals. Thus the relationship between spraint distribution and habitat quality has been statistically demonstrated in a number of studies.

Confirmation of the relationship between spraint density and habitat utilisation is available from radio-telemetry studies. Green *et. al.,* (1984) radio-tracked wild otters. Two female otters were additionally injected with a solution of radio-active zinc (Zn^{65} Cl) to label their spraints. They found that the female spraints were either concentrated at the centres of activity or at the approach to a centre of activity. They concluded that spraints have a communicative function which is related to the habitat use by the otters. Thus spraints were deposited in those areas where they were most likely to be discovered by other otters and at frequencies which were related to the value of each segment of habitat to the resident individual. Under normal circumstances there is no way to distinguish the sex of an animal by the deposition of spraint.

Having stated that spraints have been used to determine population status the present study then attempted to use the density of spraints as an indicator of habitat variables important to otters. In the present study multivariate analysis was used to investigate the density of otter spraint as an indicator of the distribution and habitat requirements of the otters on the River Allen catchment. Kruuk *et al.,* (1986) criticised relating spraint density to habitat type. However, using principle components analysis and multiple regression Macdonald and Mason (1983a) argued that the distribution of otters sites and signs could be related to habitat variables. They collected data on fifteen parameters thought to be of importance to otters. Only the distribution of sites and signs was correlated with the presence of potential holts and with mature sycamore and ash trees. They concluded that the importance of mature sycamore and ash trees may not apply to other regions. It is the fact that these trees provide places of secure refuge which make them locally important to otters, and not some inherent aspect of the trees themselves. For example, in Greece, bankside bramble (*Rubus*) was an important component of the otters' habitat in intensively cultivated regions (Macdonald & Mason 1982b).

In the present study multivariate analysis was performed on the data from all three rivers. Thus the sites with otter signs were compared to sites with no otter signs. The majority of otter spraints were found in the River Allen. No spraints were found on the West Allen. However, the multivariate analysis failed to give conclusive results concerning the habitat requirements of the otter. The only habitat variable to be correlated with the distribution of spraint was the number of mature alder trees. Since alder trees are fairly common riverside trees anyway it is difficult to propose any relationship with the distribution of otters. Moreover alder trees appear unsuitable for holts on these rivers because the roots are fine and tightly matted making them difficult to penetrate. However, the River Allen would appear to be good otter habitat in that it provides good cover in the form of dense riparian vegetation and a high density of mature bankside trees which provide many potential holts (sites for lying up during the day and/or breeding). All these factors were believed to be important in the distribution of otters on the River Teme (Macdonald, Mason & Coghill 1978). The habitat variables may have been more significantly correlated had the spraint sample size been larger. Thus the only firm conclusions that can be drawn is that more otter signs were found on stretches of the river catchment with a greater abundance of these habitat variables than on stretches were the abundance of these variables was low.

Thirteen of the fifteen spraints were found on the River Allen and two were located within the last six kilometres of the East Allen, the stretch before it joins the River Allen. No spraints were located on the West Allen. Thirteen of the spraints were found on rocks. The remaining two were found under bridges. The two equivalent stretches of the East Allen, with spraint, and the West Allen, without spraint, were tested (using χ^{2}) for the distribution of habitat variables. In order to establish an effective conservation strategy it is essential to determine which factors may be limiting the present population of otters. There were significant differences in the median cover type, amount of disturbance, potential holts, the number of mature oak trees and the depth.

The River Allens appear to support a small and fragmented otter population. The type of cover on this part of the East Allen was mainly wooded with shrubs, but not of a particularly dense nature. In contrast that of the West Allen was characterised by fewer trees, with more areas of dense vegetation. This is in accordance with the findings of Bas *et. al.*, (1984) where more spraints were found on banks with a densely wooded vegetation.

The disturbance levels were actually higher on the East Allen. Along this stretch the river is bordered by a footpath which is quite heavily used by the local people, such as walkers and anglers. The West did not have an equivalent length of path and consequently the riverside was quite inaccessible and hence human disturbance was low. Melquist and Hornocker (1983) found otters could tolerate human disturbance if the shelter was adequate. Thus although disturbance is higher on the East Allen it would appear that the presence of dense riparian vegetation and a fairly high distribution of safe refuges offsets the effects of human disturbance.

The median distribution of potential holts but not lying up places was also significantly higher on the East Allen. The distribution of mature oak trees is also higher on the East. There is an important relationship between the number of mature oak trees and the number of potential holts. The root structures of trees such as oak is very similar to that of the sycamore, which have been found to be important holt sites (Macdonald & Mason 1983a). The roots are shallow and spreading, providing shelter and forming a good roof structure to a den. Although sycamore was not found to be significant in the present study, oak may be of more local importance.

The East Allen was also deeper on average than the West and this may be of benefit to otters as the deeper pools thus present would offer a good hunting ground. This is because on an upland stream the deeper pools are likely to be easier to hunt in than rapid, rocky stretches. Trees serve other useful functions. For example the roots of some trees, such as alder, can be very effective in stabilising banks against erosion. Mason & Macdonald (1982) also noted that a substantial proportion of the food available to fish consists of invertebrates that have fallen into trees from bankside trees. They concluded that in some areas the input of terrestrial invertebrates was at least as much as the production of benthic invertebrates in the stream. Moreover they found that the most of the input occurred earlier in the year than the peak production within the stream so that at certain times of the year more than 90% of the diet of salmonids came from terrestrial species. From the comparison between the East and West Allen the present status of the otters on the River Allen catchment can be reported with most certainty. Only tentative conclusions can be drawn from the fact that there was denser cover, more potential holt sites, mature oak trees and deeper water on the stretch of the East Allen, where otter spraints were found, compared to an equivalent stretch of the West Allen, where otter spraints were not found.

Diet Analysis

Diet analysis concentrated on the fish component of the spraint. This was justified by the fact that fish have been found to form over 75% of the diet (Wise *et al.,* 1981). Other prey items, such as Amphibia, birds and mammals usually form no more than 10% of the diet respectively. Analysis of spraints revealed that eels formed the largest proportion of the diet over the study period. The frequency of occurrence of eel in the diet was found to be in the region of 40 and 79%. This was followed by perch (29-57%) and then salmonids (11-28%), Cyprinidae (10-14%) and Cobitidae (5-16%). The frequency of occurrence is thought to provide a better estimation of the otters' diet than does the bulk estimate. The bulk estimate calculations were taken from Wise (1978). However, her calculations were worked out with data from the scats of captive mink, not otter. Wise concluded that since the digestion of a mink is as thorough as that of an otter the same correction factors can be used with relative confidence for both species. However, the diet of the mink is more varied than that of the otter, comprising of a higher proportion of mammalian and bird prey so it is difficult to generalise from the mink to the otter. Moreover in the collection of the spraint, not all of the spraint is recovered and the bones identified do not necessarily come from the same fish making the bulk estimate an unreliable calculation.

The River Allen is known to support a large eel population (NRA pers. comm.). However, it has also recently been stocked with salmonids, in particular brown trout (*Salmo trutta*). The fact that a greater proportion of eel were taken in the summer months is comparable to the findings of Wise *et al.,* (1981) working in Devon. She found that otters took eels mostly in the summer and roach mainly in the winter.

One reason for this was that eels spend much of the winter lying up in the bottom mud so are not available to predation until the spring when they emerge and predation shows a marked increase. Roach may be more difficult to catch in the summer because the higher water temperatures means they have higher swimming speeds. Also roach live at quite low densities in upland rivers, such as the Allens, and may migrate in the summer.

It is surprising given the large number of salmonid fish used to stock the River Allen and East Allen that these types of fish did not form a higher proportion of the diet. It is believed that more salmonids are taken in the winter when spawning takes place. This was the finding of Jenkins and Burrows (1980) when investigating the oligotrophic tributaries of the River Dee. Another relevant factor could be that the Salmonidae family comprises many of the fastest swimming fish. They need to be able to swim quickly as they have to return upstream to spawn and hence must swim against the current and negotiate weirs and waterfalls. The long body of the eel However, is adapted for moving through thick aquatic vegetation, rather than fast movement. Eels would thus be easier to catch than salmonids. The salmonids that were caught by the otters averaged just over 100mm in length and smaller fish, juveniles, is all that would be available at this time of year. Also since smaller fish are slower swimmers than larger ones one would expect the otters to be catching these smaller prey. Cyprinidae formed the second largest proportion of the otter diet, which contrasts with Wise's findings where the proportion of perch to roach (*Rutilis rutilis*) in the diet was lower than expected from the abundance of the two species. This was possibly because otters are less keen to eat perch as they have sharp spiny dorsal fins and opercula (Wise *et al.,* 1981). This did not seem to be the case in the present study. Moreover Wise *et al.,* (1981) were studying the food of otters on a productive lake where roach would be at greater density than in upland rivers such as the Allens. Generally the results reflect the small sample of spraints collected.

The findings of Wise *et. al.,* (1981) are from the fish predation by otters at Slapton Ley, a productive freshwater lake in Devon. In this lake eel, roach and perch were particularly abundant. In contrast Wise *et. al.,* also studied the Dartmoor streams of central Devon which have a much lower density of fish. Electro-fishing on one such river produced ten times as many salmonids as eels, most of which were less than 300mm long. Nevertheless otters were found to take brown trout only three times as often as eels, presumably because they were easier to catch.

From the electro-fishing data Wise *et. al.,* (1981) were able to compare the size of fish taken with those available in the wild at the lake and river sites. She found no evidence for otters selecting fish by their size, taking different sized fish in proportion to their abundance. In the autumn salmonid fish greater than 210mm were taken much more frequently, coinciding with an increase in adult salmonids returning to spawn. In most species there was no seasonal variation.

Habitat requirements are not the only features of importance to the distribution of otters. The availability of food will probably prove to be the deciding factor. In recent years there has been no shortage of prey in the form of brown trout on the River Allen. Not only do fish stocks appear to be recovering but yearling salmon were stocked on the River Allen in 1992 and 1993 by the NRA. Although this is more for the immediate benefit of the anglers, no doubt the resident otters will benefit too. There are several plausible reasons for the absence of otters on the West Allen. Not only is there a weir in the lower stretches of the river forming an impassable barrier to migratory fish but it seems likely that the fish will avoid the zinc polluted waters. Moreover the depleted invertebrate fauna of the West Allen would mean that the food supply of the fish is also limited. Thus even without the presence of the weir it seems unlikely the heavily zinc polluted West Allen could support a fish population sufficient to meet the dietary requirements of the otter. Moreover the habitat would appear to be inadequate in the number of mature trees, potential holts and lying up places, all the variables thought to be of importance to the otter. Melquist and Hornocker (1983), working in Idaho, found that while food was the main factor influencing the distribution of otters, adequate cover was also essential. Radio tagged *Lutra canadensis* were absent from areas of ample food supply but which lacked sufficient cover and resting sites.

The East Allen appears to be a more suitable habitat for otters. It too has a impassable barrier to migratory fish and perhaps this is why there is no evidence of otters above this point. However, downstream of this natural waterfall both juvenile trout and salmon have been found. The NRA also stock the East Allen with yearling salmon so there is no shortage of food supply there. The zinc levels on the East Allen, at least for the moment, are too low to be of a significant threat to the ecosystem, although the upward trend seen in recent years may be a cause of concern. The habitat variables are also more appropriate for otters in that they offer the type of refuge they have been found to favour.

Density of otters

The home range of an otter can be quite variable in size. Erlinge (1967a) tracked two adult males, in Sweden, by following their footprints in the snow. The size of their home ranges varied from 10km to 21km. Melquist & Hornocker (1983) radio tracked American river otters in Idaho. The largest home range was of 50km in length for an adult male. Even this they believed to a conservative estimate. The home range of a juvenile increased as it got older from 15km in the autumn to 27km in the winter, reaching a maximum of 38km by the spring. Family groups had larger home ranges, averaging 34km. Adult females averaged 44km. In Perthshire, Green *et al.,* (1984), also found the home range of an adult male to be the largest at 39km followed by that of a family group of 22 and then an adult female of 16km. The sex difference in home range size could in part be explained by the difference in body size since the larger males would require more food, but the difference in range is more than can be predicted by body size alone. The lengths of the home ranges in Perthshire were and Idaho were much larger than those in Sweden. However, the authors estimates of the density of otters in each area were very similar. Erlinge estimated a density of otters between 1.7 and 2.8 per 10km of stream and Melquist and Hornocker estimated between 1.7 and 3.7 otters per 10km of streams. These estimates take into consideration such factors as spatial distribution, such as overlap between home ranges; patterns of movement, e.g. the distance covered for foraging and travel; and centres of activity, in which otters have been found to spend a high proportion of their time.

The River Allen is approximately 8km long and both of its tributaries a further 18km each. However, evidence of otters was only found on the River Allen and for a distance of 6km along the East Allen, before it joins the main river. The West Allen can be discounted as no evidence of otters was found there. Thus the total length of river on which evidence of otters was found was approximately 14km. However, otter signs have also been found on the South Tyne of which the River Allen is itself a tributary. Thus it is difficult to say how much of the home range of the River Allen otters extends into the South Tyne. That it does is probably a fair assumption since the South Tyne is a larger river that is less polluted and with fairly dense riparian vegetation. It also supports a healthy fish population. However, if we disregard the South Tyne and assume the River Allen catchment alone is being utilised as a home range the resident otter population it could support would be somewhere in the region of 2-4 otters. Given that the rivers are not ideal habitats and that zinc pollution may be affecting the food supply the actual number is probably closer to the lower estimate. Moreover the estimations were based on otters at higher densities than those on the Allen catchment and the fact that no spraints were found in the West Allen does not imply that otters are not using that part of the river.

Conclusions

The survey technique of spraint collection can give a reliable picture of the distribution of otters. If otters are to be conserved it is vital to have some idea of the habitat characteristics which they require. The present study has tentatively confirmed the importance of potential holts to the distribution of otters. The River Allens only offer a fragmented habitat to the population of otters. It seems probable that the optimum carrying capacity of the River Allens is approximately one or two otters. If otters are to be conserved their habitats must be preserved or restored. The average range of an otter is approximately ten kilometres. Many nature reserves seldom contain half this length of river. It is the water authorities and landowners rather than the reserves who will be responsible for the fate of the otters. Thus coordination between these parties is essential for the conservation of the otter. It is not just the quality of the water which will affect the survival of the otters. Since otters also utilise the river banks for resting and breeding they will require dense riparian vegetation and trees overhanging the water. These are usually the main habitat features at risk from management regimes whose main aim is to neaten the river channels and river banks, and removing trees which would otherwise obstruct machinery. However, today the management of rivers by the NRA is more sympathetic to the requirements of wildlife. Luckily certain environmental features important to otters are also of value to the people using the rivers. Unpolluted water is beneficial to the fish populations and water authorities monitor the pollution levels. In Britain as angling is such a popular pastime this an extra incentive to maintain less polluted waterways, in order to ensure good fishing grounds. As in the River Allen, some rivers are also stocked with mainly salmonids, primarily for the fishermen but to the benefit of the otters also. The clear-feeling of bankside trees is in conflict with the habitat requirements of the otter. The increased light and nutrients leads to increases in aquatic plants and riparian vegetation, which then leads to the river requiring dredging and the vegetation mowing and clearing, all of which needs to be repeated on a regular basis. Often it is necessary to remove trees which are in danger of falling into the water and posing a potential flood problem. Krausse (1977) found that in Germany and the Netherlands the costs of tree management, as opposed to tree felling, is actually less than half that of traditional bankside maintenance.

Although pollution is probably the main factor responsible for the decline of the otter population, habitat destruction has also led to the increasing fragmentation of the otter populations in Britain. The effect on habitats is to reduce their size and worse, to separate them into isolated pockets resulting in less or no exchange of individuals between them. The main concern is the isolation of breeding populations and the potential impact of inbreeding on the population. This can have serious repercussions whereby diversity in the genetic composition is lost. To prevent this process of isolation it is necessary to provide corridors between the areas of suitable habitat. Fortunately the rivers themselves can serve as just this; routes between areas of suitable habitat. Thus the most appropriate way to conserve the otter is to protect its natural habitat in conjunction with the reintroduction of otters from captive breeding programmes.

10.0 REFERENCES

Abel, P.D. and Green, D.W.J. (1981). Ecological and toxicological studies of invertebrate fauna of two rivers in the Northern Pennine orefield. pp. 109-22. In: Say, P.J. and Whitton, B. A. (Eds.) *Heavy Metals in Northern England: Environmental and Biological Aspects.* Department of Botany, University of Durham, England.

Andrews, E. and Crawford, A.K. (1986). *Otter survey of Wales 1984-85.* Vincent Wildlife Trust, London.

Ball, I.R. (1967). The relative susceptibilities of some species of freshwater fish to poisons II, Zinc. *Water Res.* **1.** 777-783.

Bas, N., Jenkins, D. and Rothery, P. (1984). The distribution of otter (*Lutra lutra*) faeces in relation to bankside vegetation on the River Dee in summer 1981. *J. of Appl. Ecol.* **21.** 507-513.

Bradley, R.W. (1977). *Interactions between Heavy Metals and Fish Populations in the Sudbury Region of Ontario.* Unpublished thesis, Laurentian University.

Brittain, J.E. (1982). Biology of Mayflies. *Ann. Rev. of Ent.* **27.** 119-147.

Brown, J.R. and Chow, L.Y.(1977). Heavy metal concentrations in Ontario fish. *Bull. Environ. Contam. Toxicol.* **17.** 190-195.

Carpenter, K. (1924). A study of the fauna of rivers polluted by lead mining in the Aberystwyth district of Cardiganshire. *Ann. Appl. Biol. 11.* 1-23.

Carpenter, K. (1926). The lead mine as an active agent in river pollution. *Ann. Appl. Biol.* **13.** 395-401.

Castel, R. W. (1976). *Fish remains in archaeology and paleo-environmental studies.* Academic Press. London.

Chanin, P. (1985). *The Natural History of Otters.* London. Croom Helm.

Chanin, P.R.F. and Jefffries, D.J. (1978). The decline of the otter, *Lutra lutra,* in Britain:An analysis of hunting records and discussion of causes. *Biol. J. Linn. Soc,* **10.** 305-328.

Chanin, P.R.F. and Linn, I. (1980). The diet of the feral mink (*Mustela vison*) in Southwest Britain. *J. of Zool.* London, **192.** 205-233.

Chapman, P.J. and Chapman, L.L. (1982). *Otter Survey of Ireland 1980-1.* Vincent Wildlife Trust.

Clifford, H.F. (1982). Life-cycles of Mayflies (Ephemeroptera) with species reference to Voltinism. *Quaest. Ent.* **18.** 15-90.

Coghill, I. S. (1988). pp 156-157. In P. Chanin, *The Natural History of Otters.* London. Croom Helm.

Conroy, J.W.H., Watt, J. B., Webb, J.B. and Jones, A. (1993). *A Guide to the Identification of Prey Remains in Otter Spraint.* Occassional Publication No. 16. The Mammal society.

Crandall, C.A. and Goodnight, C.J. (1963). The effects of sublethal concentrations of several toxicants to the common guppy, *Lebistes reticulatus. Trans. Am. Microscop. Soc.* **82.** 59-73.

Crawford, A. Jones, A. and McNulty (1979). *Otter survey of Wales 1977-78. Survey for the Promotion of Nature Conservation/NCC.* Vincent Wildlife Trust, London.

Croft, P.S. (1986). A key to the major groups of freshwater invertebrates. *Field Studies.* **6.** 531-589.

Davis, J.A. (1978). A classification of otters. pp. 14-33. In N. Duplaix (Ed.), *Otters: Proceedings of the First Meeting of the Otter Specialist Group.* IUCN, Morges,.

Department of the Environment (1976). *Methods of Biological Sampling. Handnet Sampling of Aquatic Benthic Macroinvertebrates 1978.* London, HMSO.

Elliot, J.M., Humpesch, U.H. and Macan, T.T. (1988). *Larvae of the British Ephemeroptera.* Freshwater Biological Association, Scientific Publication No. 49.

Erlinge, S. (1967a). Home range of the otter, *Lutra lutra,* in Southern Sweden. *Oikos* **18.** 186-209.

Erlinge, S. (1968a). Territoriality of the otter *Lutra lutra L.* Oikos, **19.** 81-98.

Erlinge, S. (1969). Food habits of the otter, *Lutra lutra,* and mink (*Mustela vison*) in a trout river in Southern Sweden. *Oikos,* **20.** 1-7.

Erlinge, S. (1972). Interspecific relations between otters (*Lutra lutra)* and mink (*Mustela vison*). *Oikos,* **23.** 372-335.

Fink, T.J. (1980). A comparison of the mayfly (Ephemeroptera) instar determination methods. pp 367-380. In: *Advances in Ephemeroptera Biology.* J.F.Flannagan and K.E. Marshall (Eds.). Proc. 3rd Int. Conf. on Ephemeroptera. Winnipeg, Minnesota, 1979, pub. N.Y. 552 pp.

Frost, S., Huni, A. and Kershaw, W.E (1971). Evaluation of a 'kicking' technique for sampling stream bottom fauna. *Can. J. of Zool.* **49.** 167-173.

Furse, M.T., Wright, J.F., Armitage, P.D. and Moss, D. (1981). An appraisal of pond-net samples for biological monitoring of lotic macroinvertebrates. *Water Resource,* **15.** 678-689.

Gaufin, A.R. (1973). Use of aquatic invertebrates in the assessment of water quality. pp. 96-116. In: *Biological Methods for the Assessment of Water Quality.* J. Cairns, Jr.,and K.L. Dickson (Eds.). Philadelphia, PA. *Am. Soc. Test. Mat. Sp. Publ.* 528. 256 pp.

Gaufin, A.R., Cubb, R. and Neweel, R. (1974). Studies on the tolerance of aquatic insects to low oxygen concentrations. *Great Bas. Nat.,* **34.** 45-49.

Gauss, J.D., Woods, P.E., Winner, R.W. and Skillings, J.H. (1985). Acute toxicity of copper to three life stages of Chironomous tentans as affected by water hardness-alkilinity. *Environmental Pollution Series A.* **37.** 149-157.

Gerell, R. (1967). Food selection in relation to habitat in the mink, *Mustela vison,* in Schreber in Sweden. *Oikos,* **18.** 233-246.

Green, J. and Green, R. (1980). *Otter survey of Scotland 1977-79.* Vincent Wildlife Trust, London.

Green, J. and Green, R. (1986). *Otter survey of Scotland 1984-86.* Vincent Wildlife Trust, London.

Green, J., Green, R. and Jeffries, D.J. (1984). A radio tracking survey of otters, *Lutra lutra,* on the Perthshire river system. *Lutra,* **27.** 85-145.

Harper, P.P. (1979). Plecoptera. pp 311-313.In: *Canada and its Insect Fauna.* H. V. Danks (Eds.). *Mem. Ent. Soc. Can.,* **108.** 1-573.

Hellawell, J.M. (1986). *Biological Indicators of Freshwater Pollution and Environmental Management.* London. Elsevier Applied Science Publishers.

Herbert, D.W.M. (1962). The toxicity to rainbow trout of spent stiff liquors from distillation of coal. *Ann. Appl. Biol.* **50.** 755-757.

Hider, R.C. Mason, C.F. and Bakaj, M.E. (1982). *Chlorinated hydrocarbon pesticides and polychlorinated biphenyls in freshwater fishes in the UK, 1980-1981.* Vincent Wildlife Trust.

Hillegaart, V. Sandgren, F. and Ostman, J. (1981). *Behavioural changes in captive female otters (Lutra lutra L.) around parturition.* Paper presented to the Second River Otter Symposium, University of East Anglia.

Hodson, P.V., Blunt, B.R. and Sprague, J.B. (1975). Temperature-induced changes in acute toxicity to Atlantic salmon *(Salmo salar). J. Fish. Res. Bd. Can.* **32.** 1-10.

Hynes, H.B.N. (1960). *The Biology of Polluted Waters.* Liverpool University Press. Liverpool.

Hynes, H.B.N. (1961). The invertebrate fauna of a Welsh mountain stream. *Arch. Hydrobiol.* **57.** 344-388.

Hynes, H.B.N. (1976). Biology of Plecoptera. *Ann. Rev. Ent.,* **21.** 135-153.

Hynes, H.B.N. (1977). *A Key to the Adults and Nymphs of British Stoneflies (Plecoptera).*Freshwater Biological Association. Scientific Publication No.17.

Jeffries, D.A., French, M.C. and Stebbings, R.E. (1974). *Pollution and Mammals.* Monkswood experimental Station. Report for 1972-1973. 13-15. Huntigdon.

Jenkins, D. and Burrows, G.D. (1980). Ecology of otters in northern Scotland. III. The use of faeces as indicators of otter (*Lutra lutra*) density and distribution. *J. Anim. Ecol.* **49.** 755-774.

Jenkins, D. and Harper, R.J. (1980). Ecology of otters in Northern Scotland II: Analysis of otter (*Lutra lutra*) and mink (*Mustela vison*) faeces from Deeside, North-east Scotland. *J. of Anim. Ecol.,* **49.** 737-754.

Jones, J.R.E. (1941). The oxygen consumption of *Gasterosteus aculeatus* L. in toxic solutions. *J. Exp. Biol.* **23.** 298-311.

Jones, J.R.E. (1958). A further study of the zinc polluted River Ystwyth. *J. Anim. Ecol.* **27.** 1-14.

Jones, A. N. and Howells, W.R. (1975). The partial recovery of the metal polluted River Rheidol. pp 443-459. In: M. J. Chadwick and G.T. Goodman (Eds.). *The Ecology of Resource Degradation and Renewal.* Blackwell, Oxford.

Kennedy, V.C. and Sebetich, M.J. (1976). Trace Elements in Northern Californian Streams. pp. 208-209.In: *Geological Survey Research 1976.* Washington, D.C.

Krausse, A (1977). On the effect of marginal tree rows with respect to the management of small lowland streams. *Aquatic Botany.* **3.** 185-92.

Kruuk, H. (1992). Scent marking by otters (*Lutra lutra)*: signalling the use of resources. *Behavioural Ecology.* **Vol. 3, No. 2.** 133-140.

Kruuk, H., Conroy, J. W. H., Glimmerveen, U. and Ouwerkerk, E. J. (1986). The use of spraints to survey populations of otters (*Lutra lutra*). *Biol. Conserv.* **35.** 187-194.

Laurie, R.D. and Jones, J.R.E. (1938). The faunistic recovery of a lead polluted river in north Cardiganshire, Wales. *J. Anim. Ecol.* **7.** 272-289.

Learner, M.A., Williams, R., Harcup, M. and Hughes, B.D. (1971). A survey of the macrofauna of the River Cynon, a polluted tributary of the River Taff (South Wales). *Freshwat. Biol.* **1.** *339-367.*

Lenton, E.J., Chanin, P.R.F. and Jefffries, D.J. (1980). *Otter survey of England 1977-79.* Nature Conservancy Council, London.

Lloyd, J.C. (1962). Where are the otters? *Gamekeeper and Countryside,* **65.** 299-300.

Lloyd, R. (1960). The toxicity of zinc sulphate to rainbow trout. *Ann. Appl. Biol.* **48.** 447-455.

Macan, T.T. (1958). Methods of sampling the bottom fauna in stony streams. *Mitt. int. Verein. theor. angew. Limnol.* **8.** 1-21.

Macdonald, S.M. and Mason, C.F. (1983a). Some factors influencing the distribution of otters *Lutra lutra. Mammal Rev.* **13.** 1-10.

Macdonald, S.M. and Mason, C.F. (1985). Otters, their habitat and conservation in north-east Greece. *Biol. Conserv.* **31.** 191-210.

Macdonald, S.M., Mason, C.F. and Coghill, I.S. (1978). The otter and its conservation on the River Teme catchment. *J. Appl. Ecol.* **15.** 373-384.

Martin, J.H., Knauer, G.A. and Flegal, A.R. (1980). Distribution of zinc in natural waters. pp. 193-197. In: Nriagu, J.O. (Ed.) *Zinc in the Environment Part I: Ecological Cycling.* Wiley-Interscience, New York.

Mason, C.F. and Macdonald, S.M. (1982). The input of terrestrial invertebrates from tree canopies to a stream. *Freshw. Biol.* **12.** 305-311.

Mason, C.F. and Macdonald, S.M. (1986). *Otters: Ecology and Conservation.* Cambridge. Cambridge University Press.

Mason, C.F. and Macdonald, S.M. (1987). The use of spraints for surveying otter *Lutra lutra* populations. *Biological Conservation.* **41.** 167-177.

Mason, C.F., Macdonald, S.M. and Aspden, V.J. (1982). *Metals in Freshwater Fishes in the UK.* Vincent Wildlife Trust, London.

Matter, W.J. and Ney, J.J. (1981). The impact of surface mine reclamation on headwater streams in Southwest Virginia. *Hydrobiologia,* **78.** 271-277.

Ministry of Agriculture, Foods and Fisheries (1991). Salmon Net Fisheries: Report of a Review for Salmon Net Fishing in the areas of the Yorkshire and Northumbria regions of the National Rivers Authority and the Salmon Fishery districts from the River Tweed to the River Ugie". (17th October 1991).MAFF, London.

Melquist, W.E. and Hornocker, M.G. (1983). Ecology of river otters in Idaho. *Widl. Monogr.* **83.** 1-60.

Melquist, W.E. Whitman, J.S. and Hornocker, M.G. (1981). Resource partitioning and coexistence of sympatric mink and river otter populations. pp187-220. In: J. Chapman and D. Parsley (Eds.). *Proceedings of the Worldwide Furbearer Conference.* Frostberg, Md.

Miller, J.T. Jr. (1988). *Living in the Environment.* Wadsworth Publishing Company, Belmont, CA. 603 pp.

Morgan, N.C and Egglishaw, H.J. (1965). A survey of the bottom fauna of streams in the Scottish Highlands. Part 1. Composition of the Fauna. *Hydrobiologia,* **25.** 181-211.

Nagel, B. and Landall, C.C. (1978). Resistance to anoxia of *Chironomous plumosus* and *Chironomous anthracinus* (Diptera) larvae. *Hol. Ecol.* **1.** 333-336.

Nehring, R.B. (1976). Aquatic insects as biological monitors of heavy metal pollution. *Bull. Environ. Contam. Toxicol.* **15.** 147-154.

Nehring, R.B. and Goettl, J.P., Jr. (1974). Acute toxicity of a zinc-polluted stream to four species of salmonids. *Bull. Environ. Contam. Toxicol.* **12, Vol. 4.** 464-469.

Newbold, J.D., Erman, D.C. and Roby, K.B. (1980). Effects of logging on macroinvertebrates in streams with and without buffer strips. *Can. J. Fish. Aquat, Sci.* **37.** 1076-1085.

Norris, R.H. (1986). Mine waste pollution of the Molongo River, New South Wales and the Australian Capital Territory: effectiveness of remedial works at Captains Flat mining area. *Aust. J. mar. Freshwat. Res.* **37.** 147-157.

Norris, R.H., Lake, P.S., and Swain, R. (1982). Ecological effects of mine differences on the South Esk River, North-eastern Tasmania III. Benthic macroinvertebrates. *Aust. J. mar. Freshwat. Res.* **33.** 789-809.

O'Connor, F.B. , Barwick, D., Channin, P.R.F., Frazer, J.F.D., Jeffries, D.J., Jenkins, D., Neal, E.G. and Sands, T.S. (1977). *Otters 1977.* NCC/Society for the Promotion of Nature Conservation, London.

O'Grady, K.T. and Abdullah, M.I. (1985). Mobility and residence of Zn in brown trout *Salmo trutta*: results of environmentally induced changes through transfer. *Environmental Pollution Series A.* **38.** 109-127.

Prestt, I. and Ratcliffe, D.A. (1970 I). *Effects of organochlorine insecticides on European birdlife.* Proceedings 15th International Ornothological Congress, 486-513.

Putman, R.J. (1984). Facts from faeces. *Mamm. Rev.* **14.** 79-97.

Ratcliffe, D.A. (1984). The Peregrine breeding population of the UK in 1984. *Bird Study* , **31.** 1-19.

Saether, O. A. (1980). The influence of eutrophication on deep lake benthic invertebrate communities. *Prog. Wat. Tech.* **12.** 161-180.

Sehgal, R. and Saxena, A.B. (1986). Toxicity of zinc to vivparous fish, *Lebistes reticulatus* (Peters). *Bulletin of Environmental Contamination and Toxicology.* **36.** 888-894.

Skidmore, J.F. (1965). Resistance to zinc sulphate of the zebrafish (*Brachydanio rerio*). *J. Exp. Biol.* **52.** 481-494.

Skidmore, J.F. (1974). Factors affecting the toxicity of pollutants to fish. *Vet. Rec.* May, 94. 456-458.

Speranza, A.W., Seeley, R.J., Seeley, V.A. and Perlmutter, A. (1977). The effect of zinc on reproduction in the zebrafish *Brachydanio rerio* Hamilton-Buchanan. *Environmental Pollution.* **12.** 217-222.

Sprague, J.B., Elson, P.F. and Saunders, R.L. (1965). Sublethal copper-zinc pollution in a salmon river-a field and laboratory study. *Int. J. Water Pollution.* **9.** 531-543.

Sodregen, S. (1976). Ecological effects of heavy metal discharge in a salmon river. Inst. Freshwat. Res. *Drottningholm Report,* **55.** 91-131.

Stephens, J. (1957). *The Otter Report.* UFAW, London.

Surber, E.W. (1937). Rainbow trout and bottom fauna production in one mile of stream. *Trans. Am. Fish. Soc.* **66.** 193-202.

Ter Braak, C.J.F. (1986). Cannonical correspondence analysis: A new eigenvalue technique for multivariate direct gradient analysis. *Ecology.* **67. Vol. 5.** 1167-1179.

Thom, T.J. (1990). *The Ecology of Otters (*Lutra lutra*) on the Wansbeck and the Blyth River Catchments in Northumberland.* M.sc. thesis. University of Durham. England.

Trowbridge, B.J. (1983). Olfactory communication in the European Otter, *Lutra l. lutra.* PhD thesis, University of Aberdeen.

Warnick, S.L. and Bell, H. L. (1969). The acute toxicity of some heavy metals to different species of aquatic insects. *J. Water Pollut. Control Fed.* **41.** 280-285.

Weatherley, A.H., Lake, P.S. and Rogers, S.C. (1980). Zinc pollution and the ecology of the freshwater environment. pp. 337-418. In: Nriagu, J.O. (Ed.). *Zinc in the Environment Part I: Ecological Cycling.* Wiley-Interscience, New York.

Wentsel, R., McIntosh, A., McCafferty, W.P., Atchison, G. and Anderson, V. (1977). Avoidance response of midge larvae (*Chironomous tentans*) to sediments containing heavy metals. *Hydrobiologia,* **55.** 171-175.

Wheeler, A. (1969). *The fishes of the British Isles and North-west Europe.* Macmillon. London.

Windom, H., Stickney, R., Smith, R., White, D. and Taylor, F. (1973). Arsenic, cadmium, copper, mercury and zinc in some species of North Atlantic finfish. *J Fish. Res. Board Can.* **30.** 275-279.

Winner, R.W., Boesel, M. W. and Farrel, M.P. (1980). Insect community structure as an index of heavy-metal pollution in lotic ecosystems. *Can. J. Fish. Aquat. Sci.,* **37.** 647-655.

Wise, M.H. (1978). *The Feeding Ecology of Otters and Mink in Devon.* PhD thesis, University of Exeter.

Wise, M.H., Linn, J. and Kennedy, C.R. (1981). A comparison of the feeding biology of mink (*Mustela vison*) and otter (Lutra lutra). *J. of Zool. Lond.* **195.** 181-213.

APPENDIX 1

Regression equations for the conversion of fish vertebral lengths to actual fish lengths

FL = fish length
VW = vertebrae width
VL = vertebrae length

Fish Prey	Vertebrae Type	Regression Equation	Correlation coefficient (*r*)
Eel	Thoracic	FL = 1.024VL + 1.28	0.970
	Caudal	FL = 1.152VL + 0.92	0.932
Perch	Thoracic	FL = 0.531VL + 1.32	0.992
	Caudal	FL = 0.985VL + 0.32	0.985
Salmonid	Thoracic	FL = 0.720VL + 1.21	0.98
	Caudal	FL = 0.751VL + 1.93	0.965
Stone loach	Thoracic	FL = 0.489VL + 0.52	-
	Caudal	FL = 0.593VL + 0.52	-
Percidae	Thoracic	FL = 0.506VL + 2.06	0.984
	Caudal	FL = 0.514VL + 1.27	0.988

APPENDIX II

The relative proportions of prey types in the diet of the otters on the River Allen catchment as expressed by four methods of estimation

Prey Type	Relative Frequency %	Proportion of Spraint %	Relative Estimated Bulk %	Bulk Esimate %
Eel	40	79	51	59
Perch	29	57	37	43
Salmonid	11	28	6	11
Cobitidae	5	16	10	21
Cyprinid	10	14	7	14
Unidentified	5	20	5	10

10.0 REFERENCES

Abel, P.D. and Green, D.W.J. (1981). Ecological and toxicological studies of invertebrate fauna of two rivers in the Northern Pennine orefield. pp. 109-22. In: Say, P.J. and Whitton, B. A. (Eds.) *Heavy Metals in Northern England: Environmental and Biological Aspects.* Department of Botany, University of Durham, England.

Andrews, E. and Crawford, A.K. (1986). *Otter survey of Wales 1984-85.* Vincent Wildlife Trust, London.

Ball, I.R. (1967). The relative susceptibilities of some species of freshwater fish to poisons II, Zinc. *Water Res.* **1.** 777-783.

Bas, N., Jenkins, D. and Rothery, P. (1984). The distribution of otter (*Lutra lutra*) faeces in relation to bankside vegetation on the River Dee in summer 1981. *J. of Appl. Ecol.* **21.** 507-513.

Bradley, R.W. (1977). *Interactions between Heavy Metals and Fish Populations in the Sudbury Region of Ontario.* Unpublished thesis, Laurentian University.

Brittain, J.E. (1982). Biology of Mayflies. *Ann. Rev. of Ent.* **27.** 119-147.

Brown, J.R. and Chow, L.Y.(1977). Heavy metal concentrations in Ontario fish. *Bull. Environ. Contam. Toxicol.* **17.** 190-195.

Carpenter, K. (1924). A study of the fauna of rivers polluted by lead mining in the Aberystwyth district of Cardiganshire. *Ann. Appl. Biol. 11.* 1-23.

Carpenter, K. (1926). The lead mine as an active agent in river pollution. *Ann. Appl. Biol.***13.** 395-401.

Castel, R. W. (1976). *Fish remains in archaeology and paleo-environmental studies.* Academic Press. London.

Chanin, P. (1985). *The Natural History of Otters.* London. Croom Helm.

Chanin, P.R.F. and Jefffries, D.J. (1978). The decline of the otter, *Lutra lutra*, in Britain:An analysis of hunting records and discussion of causes. *Biol. J. Linn. Soc,* **10.** 305-328.

Chanin, P.R.F. and Linn, I. (1980). The diet of the feral mink (*Mustela vison*) in Southwest Britain. *J. of Zool.* London, **192.** 205-233.

Chapman, P.J. and Chapman, L.L. (1982).*Otter Survey of Ireland 1980-1.* Vincent Wildlife Trust.

Clifford, H.F. (1982). Life-cycles of Mayflies (Ephemeroptera) with species reference to Voltinism. *Quaest. Ent.* **18.** 15-90.

Coghill, I. S. (1988). pp 156-157. In P. Chanin, *The Natural History of Otters.* London. Croom Helm.

Conroy, J.W.H., Watt, J. B., Webb, J.B. and Jones, A. (1993). *A Guide to the Identification of Prey Remains in Otter Spraint.* Occassional Publication No. 16. The Mammal society.

Crandall, C.A. and Goodnight, C.J. (1963). The effects of sublethal concentrations of several toxicants to the common guppy, *Lebistes reticulatus. Trans. Am. Microscop. Soc.* **82.** 59-73.

Crawford, A. Jones, A. and McNulty (1979). *Otter survey of Wales 1977-78. Survey for the Promotion of Nature Conservation/NCC.* Vincent Wildlife Trust, London.

Croft, P.S. (1986). A key to the major groups of freshwater invertebrates. *Field Studies.* **6.** 531-589.

Davis, J.A. (1978). A classification of otters. pp. 14-33. In N. Duplaix (Ed.), *Otters: Proceedings of the First Meeting of the Otter Specialist Group.* IUCN, Morges,.

Department of the Environment (1976). *Methods of Biological Sampling. Handnet Sampling of Aquatic Benthic Macroinvertebrates 1978.* London, HMSO.

Elliot, J.M., Humpesch, U.H. and Macan, T.T. (1988). *Larvae of the British Ephemeroptera.* Freshwater Biological Association, Scientific Publication No. 49.

Erlinge, S. (1967a). Home range of the otter, *Lutra lutra,* in Southern Sweden. *Oikos* **18.** 186-209.

Erlinge, S. (1968a). Territoriality of the otter *Lutra lutra L.* Oikos, **19.** 81-98.

Erlinge, S. (1969). Food habits of the otter, *Lutra lutra,* and mink (*Mustela vison*) in a trout river in Southern Sweden. *Oikos,* **20.** 1-7.

Erlinge, S. (1972). Interspecific relations between otters (*Lutra lutra)* and mink (*Mustela vison*). *Oikos,* **23.** 372-335.

Fink, T.J. (1980). A comparison of the mayfly (Ephemeroptera) instar determination methods. pp 367-380. In: *Advances in Ephemeroptera Biology.* J.F.Flannagan and K.E. Marshall (Eds.). Proc. 3rd Int. Conf. on Ephemeroptera. Winnipeg, Minnesota, 1979, pub. N.Y. 552 pp.

Frost, S., Huni, A. and Kershaw, W.E (1971). Evaluation of a 'kicking' technique for sampling stream bottom fauna. *Can. J. of Zool.* **49.** 167-173.

Furse, M.T., Wright, J.F., Armitage, P.D. and Moss, D. (1981). An appraisal of pond-net samples for biological monitoring of lotic macroinvertebrates. *Water Resource,* **15.** 678-689.

Gaufin, A.R. (1973). Use of aquatic invertebrates in the assessment of water quality. pp. 96-116. In: *Biological Methods for the Assessment of Water Quality.* J. Cairns, Jr.,and K.L. Dickson (Eds.). Philadelphia, PA. *Am. Soc. Test. Mat. Sp. Publ.* 528. 256 pp.

Gaufin, A.R., Cubb, R. and Neweel, R. (1974). Studies on the tolerance of aquatic insects to low oxygen concentrations. *Great Bas. Nat.,* **34.** 45-49.

Gauss, J.D., Woods, P.E., Winner, R.W. and Skillings, J.H. (1985). Acute toxicity of copper to three life stages of Chironomous tentans as affected by water hardness-alkilinity. *Environmental Pollution Series A.* **37.** 149-157.

Gerell, R. (1967). Food selection in relation to habitat in the mink, *Mustela vison,* in Schreber in Sweden. *Oikos,* **18.** 233-246.

Green, J. and Green, R. (1980). *Otter survey of Scotland 1977-79.* Vincent Wildlife Trust, London.

Green, J. and Green, R. (1986). *Otter survey of Scotland 1984-86.* Vincent Wildlife Trust, London.

Green, J., Green, R. and Jeffries, D.J. (1984). A radio tracking survey of otters, *Lutra lutra,* on the Perthshire river system. *Lutra,* **27.** 85-145.

Harper, P.P. (1979). Plecoptera. pp 311-313.In: *Canada and its Insect Fauna.* H. V. Danks (Eds.). *Mem. Ent. Soc. Can.,* **108.** 1-573.

Hellawell, J.M. (1986). *Biological Indicators of Freshwater Pollution and Environmental Management.* London. Elsevier Applied Science Publishers.

Herbert, D.W.M. (1962). The toxicity to rainbow trout of spent stiff liquors from distillation of coal. *Ann. Appl. Biol.* **50.** 755-757.

Hider, R.C. Mason, C.F. and Bakaj, M.E. (1982). *Chlorinated hydrocarbon pesticides and polychlorinated biphenyls in freshwater fishes in the UK, 1980-1981.* Vincent Wildlife Trust.

Hillegaart, V. Sandgren, F. and Ostman, J. (1981). *Behavioural changes in captive female otters (Lutra lutra L.) around parturition.* Paper presented to the Second River Otter Symposium, University of East Anglia.

Hodson, P.V., Blunt, B.R. and Sprague, J.B. (1975). Temperature-induced changes in acute toxicity to Atlantic salmon (*Salmo salar*). *J. Fish. Res. Bd. Can.* **32.** 1-10.

Hynes, H.B.N. (1960). *The Biology of Polluted Waters.* Liverpool University Press. Liverpool.

Hynes, H.B.N. (1961). The invertebrate fauna of a Welsh mountain stream. *Arch. Hydrobiol.* **57.** 344-388.

Hynes, H.B.N. (1976). Biology of Plecoptera. *Ann. Rev. Ent.,* **21.** 135-153.

Hynes, H.B.N. (1977). *A Key to the Adults and Nymphs of British Stoneflies (Plecoptera).*Freshwater Biological Association. Scientific Publication No.17.

Jeffries, D.A., French, M.C. and Stebbings, R.E. (1974). *Pollution and Mammals.* Monkswood experimental Station. Report for 1972-1973. 13-15. Huntigdon.

Jenkins, D. and Burrows, G.D. (1980). Ecology of otters in northern Scotland. III. The use of faeces as indicators of otter (*Lutra lutra*) density and distribution. *J. Anim. Ecol.* **49.** 755-774.

Jenkins, D. and Harper, R.J. (1980). Ecology of otters in Northern Scotland II: Analysis of otter (*Lutra lutra*) and mink (*Mustela vison*) faeces from Deeside, North-east Scotland. *J. of Anim. Ecol.,* **49.** 737-754.

Jones, J.R.E. (1941). The oxygen consumption of *Gasterosteus aculeatus* L. in toxic solutions. *J. Exp. Biol.* **23.** 298-311.

Jones, J.R.E. (1958). A further study of the zinc polluted River Ystwyth. *J. Anim. Ecol.* **27.** 1-14.

Jones, A. N. and Howells, W.R. (1975). The partial recovery of the metal polluted River Rheidol. pp 443-459. In: M. J. Chadwick and G.T. Goodman (Eds.). *The Ecology of Resource Degradation and Renewal.* Blackwell, Oxford.

Kennedy, V.C. and Sebetich, M.J. (1976). Trace Elements in Northern Californian Streams. pp. 208-209.In: *Geological Survey Research 1976.* Washington, D.C.

Krausse, A (1977). On the effect of marginal tree rows with respect to the management of small lowland streams. *Aquatic Botany.* **3.** 185-92.

Kruuk, H. (1992). Scent marking by otters (*Lutra lutra)*: signalling the use of resources. *Behavioural Ecology.* **Vol. 3, No. 2.** 133-140.

Kruuk, H., Conroy, J. W. H., Glimmerveen, U. and Ouwerkerk, E. J. (1986). The use of spraints to survey populations of otters (*Lutra lutra*). *Biol. Conserv.* **35.** 187-194.

Laurie, R.D. and Jones, J.R.E. (1938). The faunistic recovery of a lead polluted river in north Cardiganshire, Wales. *J. Anim. Ecol.* **7.** 272-289.

Learner, M.A., Williams, R., Harcup, M. and Hughes, B.D. (1971). A survey of the macrofauna of the River Cynon, a polluted tributary of the River Taff (South Wales). *Freshwat. Biol.* **1.** *339-367.*

Lenton, E.J., Chanin, P.R.F. and Jefffries, D.J. (1980). *Otter survey of England 1977-79.* Nature Conservancy Council, London.

Lloyd, J.C. (1962). Where are the otters? *Gamekeeper and Countryside,* **65.** 299-300.

Lloyd, R. (1960). The toxicity of zinc sulphate to rainbow trout. *Ann. Appl. Biol.* **48.** 447-455.

Macan, T.T. (1958). Methods of sampling the bottom fauna in stony streams. *Mitt. int. Verein. theor. angew. Limnol.* **8.** 1-21.

Macdonald, S.M. and Mason, C.F. (1983a). Some factors influencing the distribution of otters *Lutra lutra*. *Mammal Rev.* **13.** 1-10.

Macdonald, S.M. and Mason, C.F. (1985). Otters, their habitat and conservation in north-east Greece. *Biol. Conserv.* **31.** 191-210.

Macdonald, S.M., Mason, C.F. and Coghill, I.S. (1978). The otter and its conservation on the River Teme catchment. *J. Appl. Ecol.* **15.** 373-384.

Martin, J.H., Knauer, G.A. and Flegal, A.R. (1980). Distribution of zinc in natural waters. pp. 193-197. In: Nriagu, J.O. (Ed.) *Zinc in the Environment Part I: Ecological Cycling.* Wiley-Interscience, New York.

Mason, C.F. and Macdonald, S.M. (1982). The input of terrestrial invertebrates from tree canopies to a stream. *Freshw. Biol.* **12.** 305-311.

Mason, C.F. and Macdonald, S.M. (1986). *Otters: Ecology and Conservation.* Cambridge. Cambridge University Press.

Mason, C.F. and Macdonald, S.M. (1987). The use of spraints for surveying otter *Lutra lutra* populations. *Biological Conservation.* **41.** 167-177.

Mason, C.F., Macdonald, S.M. and Aspden, V.J. (1982). *Metals in Freshwater Fishes in the UK.* Vincent Wildlife Trust, London.

Matter, W.J. and Ney, J.J. (1981). The impact of surface mine reclamation on headwater streams in Southwest Virginia. *Hydrobiologia,* **78.** 271-277.

Ministry of Agriculture, Foods and Fisheries (1991). Salmon Net Fisheries: Report of a Review for Salmon Net Fishing in the areas of the Yorkshire and Northumbria regions of the National Rivers Authority and the Salmon Fishery districts from the River Tweed to the River Ugie". (17th October 1991).MAFF, London.

Melquist, W.E. and Hornocker, M.G. (1983). Ecology of river otters in Idaho. *Widl. Monogr.* **83.** 1-60.

Melquist, W.E. Whitman, J.S. and Hornocker, M.G. (1981). Resource partitioning and coexistence of sympatric mink and river otter populations. pp187-220. In: J. Chapman and D. Parsley (Eds.). *Proceedings of the Worldwide Furbearer Conference.* Frostberg, Md.

Miller, J.T. Jr. (1988). *Living in the Environment.* Wadsworth Publishing Company, Belmont, CA. 603 pp.

Morgan, N.C and Egglishaw, H.J. (1965). A survey of the bottom fauna of streams in the Scottish Highlands. Part 1. Composition of the Fauna. *Hydrobiologia,* **25.** 181-211.

Nagel, B. and Landall, C.C. (1978). Resistance to anoxia of *Chironomous plumosus* and *Chironomous anthracinus* (Diptera) larvae. *Hol. Ecol.* **1.** 333-336.

Nehring, R.B. (1976). Aquatic insects as biological monitors of heavy metal pollution. *Bull. Environ. Contam. Toxicol.* **15.** 147-154.

Nehring, R.B. and Goettl, J.P., Jr. (1974). Acute toxicity of a zinc-polluted stream to four species of salmonids. *Bull. Environ. Contam. Toxicol.* **12, Vol. 4.** 464-469.

Newbold, J.D., Erman, D.C. and Roby, K.B. (1980). Effects of logging on macroinvertebrates in streams with and without buffer strips. *Can. J. Fish. Aquat, Sci.* **37.** 1076-1085.

Norris, R.H. (1986). Mine waste pollution of the Molongo River, New South Wales and the Australian Capital Territory: effectiveness of remedial works at Captains Flat mining area. *Aust. J. mar. Freshwat. Res.* **37.** 147-157.

Norris, R.H., Lake, P.S., and Swain, R. (1982). Ecological effects of mine differences on the South Esk River, North-eastern Tasmania III. Benthic macroinvertebrates. *Aust. J. mar. Freshwat. Res.* **33.** 789-809.

O'Connor, F.B. , Barwick, D., Channin, P.R.F., Frazer, J.F.D., Jeffries, D.J., Jenkins, D., Neal, E.G. and Sands, T.S. (1977). *Otters 1977.* NCC/Society for the Promotion of Nature Conservation, London.

O'Grady, K.T. and Abdullah, M.I. (1985). Mobility and residence of Zn in brown trout *Salmo trutta*: results of environmentally induced changes through transfer. *Environmental Pollution Series A.* **38.** 109-127.

Prestt, I. and Ratcliffe, D.A. (1970 I). *Effects of organochlorine insecticides on European birdlife.* Proceedings 15th International Ornothological Congress, 486-513.

Putman, R.J. (1984). Facts from faeces. *Mamm. Rev.* **14.** 79-97.

Ratcliffe, D.A. (1984). The Peregrine breeding population of the UK in 1984. *Bird Study* , **31.** 1-19.

Saether, O. A. (1980). The influence of eutrophication on deep lake benthic invertebrate communities. *Prog. Wat. Tech.* **12.** 161-180.

Sehgal, R. and Saxena, A.B. (1986). Toxicity of zinc to vivparous fish, *Lebistes reticulatus* (Peters). *Bulletin of Environmental Contamination and Toxicology.* **36.** 888-894.

Skidmore, J.F. (1965). Resistance to zinc sulphate of the zebrafish (*Brachydanio rerio*). *J. Exp. Biol.* **52.** 481-494.

Skidmore, J.F. (1974). Factors affecting the toxicity of pollutants to fish. *Vet. Rec.* May, 94. 456-458.

Speranza, A.W., Seeley, R.J., Seeley, V.A. and Perlmutter, A. (1977). The effect of zinc on reproduction in the zebrafish *Brachydanio rerio* Hamilton-Buchanan. *Environmental Pollution.* **12.** 217-222.

Sprague, J.B., Elson, P.F. and Saunders, R.L. (1965). Sublethal copper-zinc pollution in a salmon river-a field and laboratory study. *Int. J. Water Pollution.* **9.** 531-543.

Sodregen, S. (1976). Ecological effects of heavy metal discharge in a salmon river. Inst. Freshwat. Res. *Drottningholm Report,* **55.** 91-131.

Stephens, J. (1957). *The Otter Report.* UFAW, London.

Surber, E.W. (1937). Rainbow trout and bottom fauna production in one mile of stream. *Trans. Am. Fish. Soc.* **66.** 193-202.

Ter Braak, C.J.F. (1986). Cannonical correspondence analysis: A new eigenvalue technique for multivariate direct gradient analysis. *Ecology.* **67. Vol. 5.** 1167-1179.

Thom, T.J. (1990). *The Ecology of Otters (*Lutra lutra*) on the Wansbeck and the Blyth River Catchments in Northumberland.* M.sc. thesis. University of Durham. England.

Trowbridge, B.J. (1983). Olfactory communication in the European Otter, *Lutra l. lutra.* PhD thesis, University of Aberdeen.

Warnick, S.L. and Bell, H. L. (1969). The acute toxicity of some heavy metals to different species of aquatic insects. *J. Water Pollut. Control Fed.* **41.** 280-285.

Weatherley, A.H., Lake, P.S. and Rogers, S.C. (1980). Zinc pollution and the ecology of the freshwater environment. pp. 337-418. In: Nriagu, J.O. (Ed.). *Zinc in the Environment Part I: Ecological Cycling.* Wiley-Interscience, New York.

Wentsel, R., McIntosh, A., McCafferty, W.P., Atchison, G. and Anderson, V. (1977). Avoidance response of midge larvae (*Chironomous tentans*) to sediments containing heavy metals. *Hydrobiologia,* **55.** 171-175.

Wheeler, A. (1969). *The fishes of the British Isles and North-west Europe.* Macmillon. London.

Windom, H., Stickney, R., Smith, R., White, D. and Taylor, F. (1973). Arsenic, cadmium, copper, mercury and zinc in some species of North Atlantic finfish. *J Fish. Res. Board Can.* **30.** 275-279.

Winner, R.W., Boesel, M. W. and Farrel, M.P. (1980). Insect community structure as an index of heavy-metal pollution in lotic ecosystems. *Can. J. Fish. Aquat. Sci.,* **37.** 647-655.

Wise, M.H. (1978). *The Feeding Ecology of Otters and Mink in Devon.* PhD thesis, University of Exeter.

Wise, M.H., Linn, J. and Kennedy, C.R. (1981). A comparison of the feeding biology of mink (*Mustela vison*) and otter (Lutra lutra). *J. of Zool. Lond.* **195.** 181-213.

APPENDIX 1

Regression equations for the conversion of fish vertebral lengths to actual fish lengths

FL = fish length
VW = vertebrae width
VL = vertebrae length

Fish Prey	Vertebrae Type	Regression Equation	Correlation coefficient (*r*)
Eel	Thoracic	FL = 1.024VL + 1.28	0.970
	Caudal	FL = 1.152VL + 0.92	0.932
Perch	Thoracic	FL = 0.531VL + 1.32	0.992
	Caudal	FL = 0.985VL + 0.32	0.985
Salmonid	Thoracic	FL = 0.720VL + 1.21	0.98
	Caudal	FL = 0.751VL + 1.93	0.965
Stone loach	Thoracic	FL = 0.489VL + 0.52	-
	Caudal	FL = 0.593VL + 0.52	-
Percidae	Thoracic	FL = 0.506VL + 2.06	0.984
	Caudal	FL = 0.514VL + 1.27	0.988

APPENDIX II

The relative proportions of prey types in the diet of the otters on the River Allen catchment as expressed by four methods of estimation

Prey Type	Relative Frequency %	Proportion of Spraint %	Relative Estimated Bulk %	Bulk Esimate %
Eel	40	79	51	59
Perch	29	57	37	43
Salmonid	11	28	6	11
Cobitidae	5	16	10	21
Cyprinid	10	14	7	14
Unidentified	5	20	5	10